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Further research into the glaciation of convective clouds of the type that produce lightning has revealed that the early stages of ice formation can be detected by measurement of the supercooled droplet radius - a result which also has climatological implications.

Further laboratory experiments have shown that the most effective methods of lightning initiation are likely to involve supercooled raindrops, with threshold fields around 300kV/m.

A new model of thundercloud electrification and lightning production has been developed, from which it is possible to deduce the sensitivity of lightning frequency to meteorological and cloud microphysical parameters.

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THE INITIATION OF LIGHTNING AND THE GROWTH OF ELECTRIC FIELDS IN THUNDERSTORMS

Second Annual Report to the European Office of Aerospace Research and Development

(Attn. Ms Janet Johnston)

Contract No. F49620-92-J-0020

by

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December 1993

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1. PREAMBLE

It was predicted, in the concluding paragraph of the First Annual Report, that the primary research focus in the second year of work under the contract, would be in three areas:-

(1) Extension of studies of thundercloud glaciation.

(2) Extension of laboratory studies of lightning initiation.

(3) Development of theoretical and computational studies of thunderstorm electrification / lightning problems.

It has indeed transpired that major attention has been devoted to these three topics, with papers having been accepted for publication in (1) and (2), and a paper shortly to be submitted for publication in (3).

Section 2 of this report consists of a preprint of a paper by a colleague and myself, which has been accepted for publication in the Quarterly Journal of the Royal Meteorological Society. It is concerned with topic (1).

Section 3 of this report consists of a preprint of a paper by a colleague and myself, which will be published in the Proceedings of the First International Conference on Lightning, held in Vitrac, France in June 1992.

Section 4 of this report consists of a description of a newly developed model of thundercloud electrification and lightning, together with some specimen results. It predicts (for the first time, we believe) the frequency of lightning production as a function of significant meteorological and microphysical input parameters; and it draws on the results of research conducted earlier, under this contract.

SECTION 2. RESEARCH ON THE GLACIATION OF CONVECTIVE CLOUDS

INFLUENCE OF GLACIATION ON AN EFFECTIVE-RADIUS PARAMETERISATION

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ABSTRACT

A recent study (Blyth and Latham 1991) of ice-free, non-precipitating sub-adiabatic cumulus clouds, involving the examination of data from multiple-penetration airborne experiments conducted in Montana and New Mexico, showed that the effective radius r_{eff} - a parameter of central relevance to global climate models - was essentially independent, at any particular level in the clouds and for any spatial scale of measurement, of the liquid water content L and the droplet concentration N (i.e. r_{eff} was independent of the extent to which the cloud was diluted by entrainment of environmental air). This finding led to the prediction that r_{eff} may be simply expressed, at any location in the clouds, by the relationship $r_{eff} = r_{ad}$, where the "adiabatic radius" r_{ad} is given by

$$r_{ad} = \left(\frac{3}{4\pi} \frac{1}{\rho_w} \frac{L_{ad}}{N_{ad}} \right)^{1/3} .$$

In this equation, ρ_w is the density of liquid water and N_{ad} and L_{ad} are the "adiabatic" values of L and N respectively. Thus the predicted "non-dimensional effective radius" is given by

$$A = \frac{r_{eff}}{r_{ad}} = 1 .$$

Analysis of the airborne data for the Montanan cumuli (35 cloud penetrations) revealed that $A = 0.83 \pm 0.07$, and for the New Mexican cumuli (25 penetrations) $A = 0.93 \pm 0.05$ in reasonable agreement with the predictions.

It was mentioned in Blyth and Latham (1991) that preliminary analysis indicated that when these clouds started to glaciate (or more precisely, in those regions of the clouds where glaciation had commenced) the climatological parameter A increased.

This indication has now been subjected to further study, which forms the topic of this note.

The analysis presented herein is confined to data from airborne studies of New Mexican cumuli in the summer of 1987. The clouds were studied using the NCAR King Air cloud physics research airplane with most microphysical parameters being measured at a rate of 10 Hz, corresponding to a spatial scale of about 10 m. The plots presented herein, however, are 1 second averages. The droplet spectra were not corrected for coincidence errors discussed by Cooper (1988) and Brenguir (1989). Cooper suggested that distortions of the true spectra could occur if the measured concentration,N, is above 500 cm^{-3}, but that there could be effects if $N > 100$ cm^{-3}. Since the parameter discussed in this paper, A, was found to be independent of N except for the lowest values it is unlikely that coincidences significantly influenced the results discussed in this paper. Furthermore, it was rare for the number concentration to exceed 500 cm^{-3}.

We were careful to eliminate spectra that were contaminated by ice particles (Gardiner and Hallett 1985) by monitoring, in regions of cloud containing ice, when

the liquid water content measured by the FSSP was more than about one and a half times that measured by the Johnson-Williams device.

The clouds were typically 2 to 3 km deep with base and summit temperatures in the ranges ? to ? and ? to ? respectively. They were generally strongly subadiabatic, the normalised liquid-water-content L/L_{ad} (penetration averages) lying generally in the range 0.2 to 0.4: Some regions were observed, however, where $L/L_{ad} \approx 1$.

Flights were made through the clouds at a variety of levels. The presence of ice in these clouds - together with the concentrations, sizes and shapes of the ice particles - was established by means of the PMS 2DC and 2DP probes.

In many cases, no ice particles were detected during penetrations in the early stages of the cloud development. In this situation, the effective radius r_{eff} was found to be essentially independent of the ratio L/L_{ad} - which parameter is an indication of the extent to which the region of cloud traversed was diluted by entrainment - and the prediction that $A = r_{eff}/r_{ad} = 1$ was approximately confirmed. This finding is illustrated in Figure 1, which is a histogram of A produced by accumulating data from many penetrations through ice free regions of 11 clouds. The average value of A was 0.91 and the standard deviation was 0.33. Deviations in r_{eff} from the adiabatic value when L/L_{ad} is low is largely responsible for the large standard deviation. There are many instances, when the number of drops has been substantially depleted due to entrainment, that the size of the remaining drops is significantly smaller. There are, however, a larger number of instances when, despite the low values of N and L/L_{ad}, the relationship $A \approx 1$ remains true.

While Bower and Choularton (1992) also found r_{eff} to remain essentially unaffected by entrainment in a few cumulus clouds measured in Montana, they suggested that a more appropriate parameterisation for the effective radius in continental cumulus clouds is given by simply setting r_{eff} to a fixed value of between 9 and 10 μm. The overall average value of r_{eff} in ice-free regions of New Mexican cumuli is 8.5 μm, slightly outside this range, with a standard deviation of 3 μm.

Noticable changes in the parameter A began to occur when the probes revealed the presence of ice particles in the midst of the cloud.

Figure 2 presents 1 sec (100 m) average plots of L/L_{ad} against the effective radius parameter A for many penetrations made through 11 cumulus clouds. The crosses correspond to measurements made when the ice-particle concentration determined from the 2DC, $N_C = 0$, and the hollow squares relate to conditions where N_C exceeded 10 L^{-1} of air. We see from Figure 2 that although the "ice-free" points correspond to A-values close to 1.0, the A-values for 100 m cloud sections containing ice were often significantly in excess of 1.0. The trend is illustrated more clearly when data from a single cloud is examined; these data are shown in Figure 3. The values of A are larger in regions containing more than 10 L^{-1} of ice than in regions containing no ice.

Figure 4 illustrates the temporal variations of the droplet concentration N, ice particle concentration from the 2DC, N_C, liquid water content L, determined from the FSSP, and the vertical and horizontal wind for a typical penetration in this cloud. Notice that ice is present in regions of cloud with substantial amounts of liquid water content. However, the concentration of ice ($N_C \approx 20\ L^{-1}$) is 4 orders of magnitude smaller than the concentration of cloud droplets ($N \approx 5\times10^5$ L^{-1}). Figure 5 shows shadows of ice particles sampled by the 2DC collected during the penetrations shown in Figure 4. The particles are a mixture of unrimed and rimed stellars existing in a region of cloud with negligible updraught, but substantial liquid.

The physics of this effect can be understood qualitatively as follows:-

Once ice particles have been created in a supercooled region of cloud they will compete with the (generally much more numerous) cloud droplets for water vapour, in order to grow. Initially, when ice is first produced, this competition will be negligible, because the solid particles are too few and too small to exercise a significant effect. In this situation the value of A will be around or somewhat less than 1.0, as shown in Figure 1 and - in more detail - in Blyth and Latham (1991). However, as glaciation proceeds and ice particles grow in number and size the competition will become significant and perhaps eventually dominant. In this circumstance the vapour pressure in this region will fall, possibly to below the saturation value with respect to water, whilst remaining above the saturation value with respect to ice. In this latter situation, the ice particles will continue to grow while the droplets will evaporate. These strongly sub-adiabatic clouds tend to contain high concentrations of relatively small droplets produced by recent activation of entrained cloud concentration nuclei (Ref?). When the vapour pressure falls below the water saturation value these small droplets will tend to evaporate completely, producing an increase in the average droplet size and associated effective radius r_{eff} (and thus A), as observed (for example, Figures 2 and 5).

Ice particles in concentrations of a few per litre are about five orders of magnitude less numerous than the supercooled water droplets with which they coexist. However, in a slightly water supersaturated environment characteristic of these cumulus clouds before glaciation is well advanced, each one of them consumes vapour from the environment much more rapidly than individual neighbouring droplets, in part because they are aspherical and (through growing faster) larger, but principally because the supersaturation with respect to ice is much greater than that over water. Characteristic values for these enhanced-growth-rate factors are about 3 orders of magnitude in the latter case (taking -10 °C as a typical temperature) and between 1 and 2 orders of magnitude in the former. Thus it is not surprising that the values of the effective-radius parameter depart from the "ice-free" theoretical value of 1 when ice crystal concentrations of a few per litre exist within the clouds.

The foregoing scenario represents only one possible way in which developing glaciation can change the water droplet characteristics of cumulus clouds, and thereby the effective radius. An alternative effect, a decrease in A below the idealised value, rather than an increase - may be produced when the supersaturation with respect to water falls (as a consequence of depletion of water vapour by the growing ice particles), without significant total evaporation of cloud droplets. In this case, the effective radius r_{eff}, and thereby A will diminish. Thus the overall influence of glaciation on r_{eff}, and hence A, will be a function of ice particle sizes and concentrations, together with the droplet size distributions, which themselves are generally influenced by entrainment. It is planned to explore this range of possibilities further, by means of modelling and more extensive data anlaysis.

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FIGURE LEGENDS

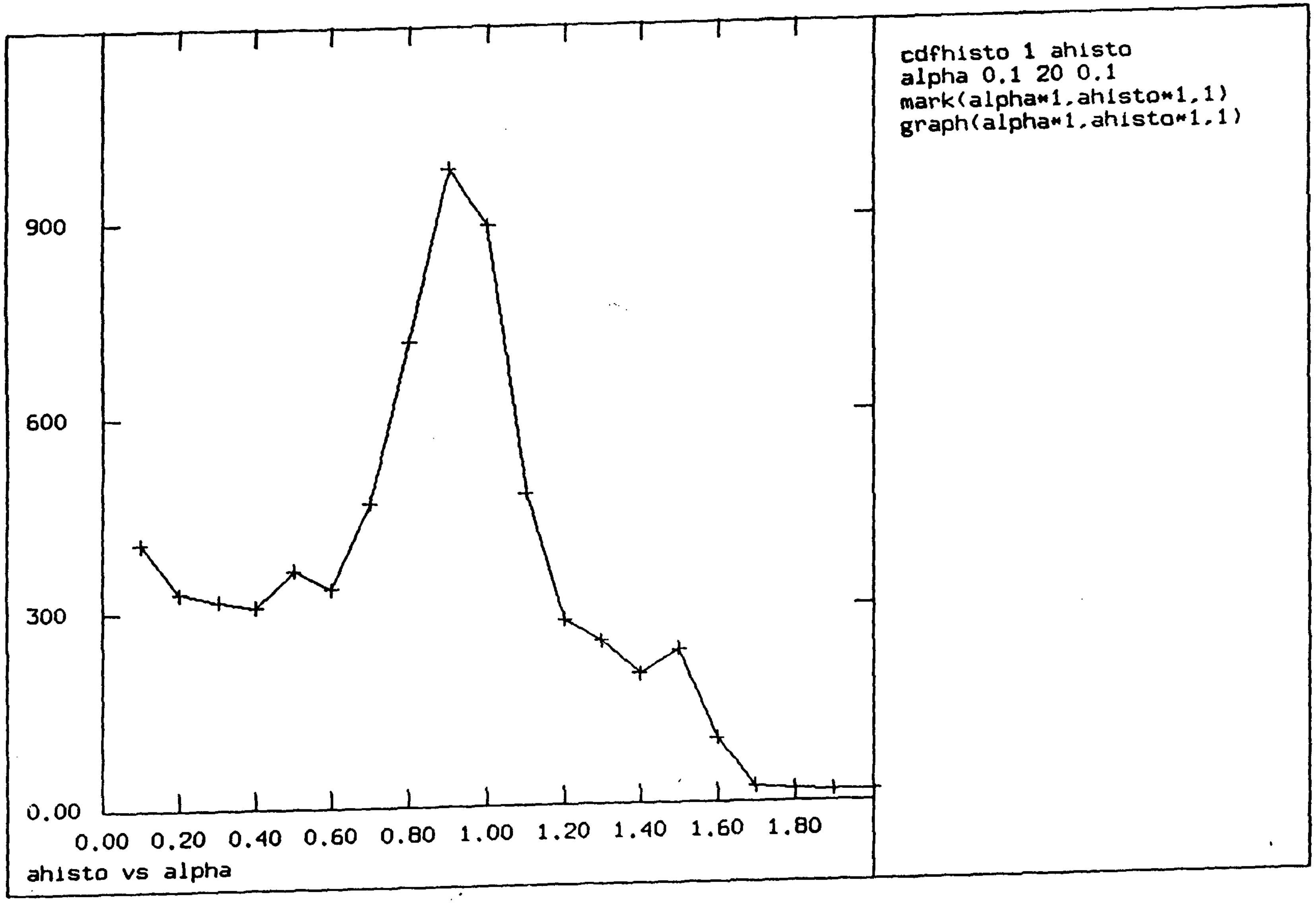
Fig. 1: Histogram of $A = r_{eff} / r_{ad}$ for all ice-free regions of cloud studied during the project.

Fig. 2: Plot of A versus L / L_{ad} for regions of cloud with: × - $N_C = 0$; □ - $N_C \geq 10$ L^{-1} from 11 cumulus clouds.

Fig. 3: Plot of A versus L / L_{ad} for regions of cloud with: × - $N_C = 0$; □ - $N_C \geq 10$ L^{-1} ~~from~~ 19 August 1987.

Fig. 4: Time series of, in ascending order, liquid water content, L, droplet concentration N, ice particle concentration measured by the 2DC, N_C, and the vertical and horizontal wind for a penetration made on 19 August, 1987. The wind vectors are constructed with the horizontal wind along the track of the aircraft and the vertical wind.

Fig. 5: 2D images from the 2DC and 2DP probes from the region of cloud indicated by **A** in Figure 4. The text under each strip of images refers to the probe, date, and beginning and end time of the images. The distance between the horizontal lines is approximately 800 and 6400 μm for the 2DC and 2DP probes respectively.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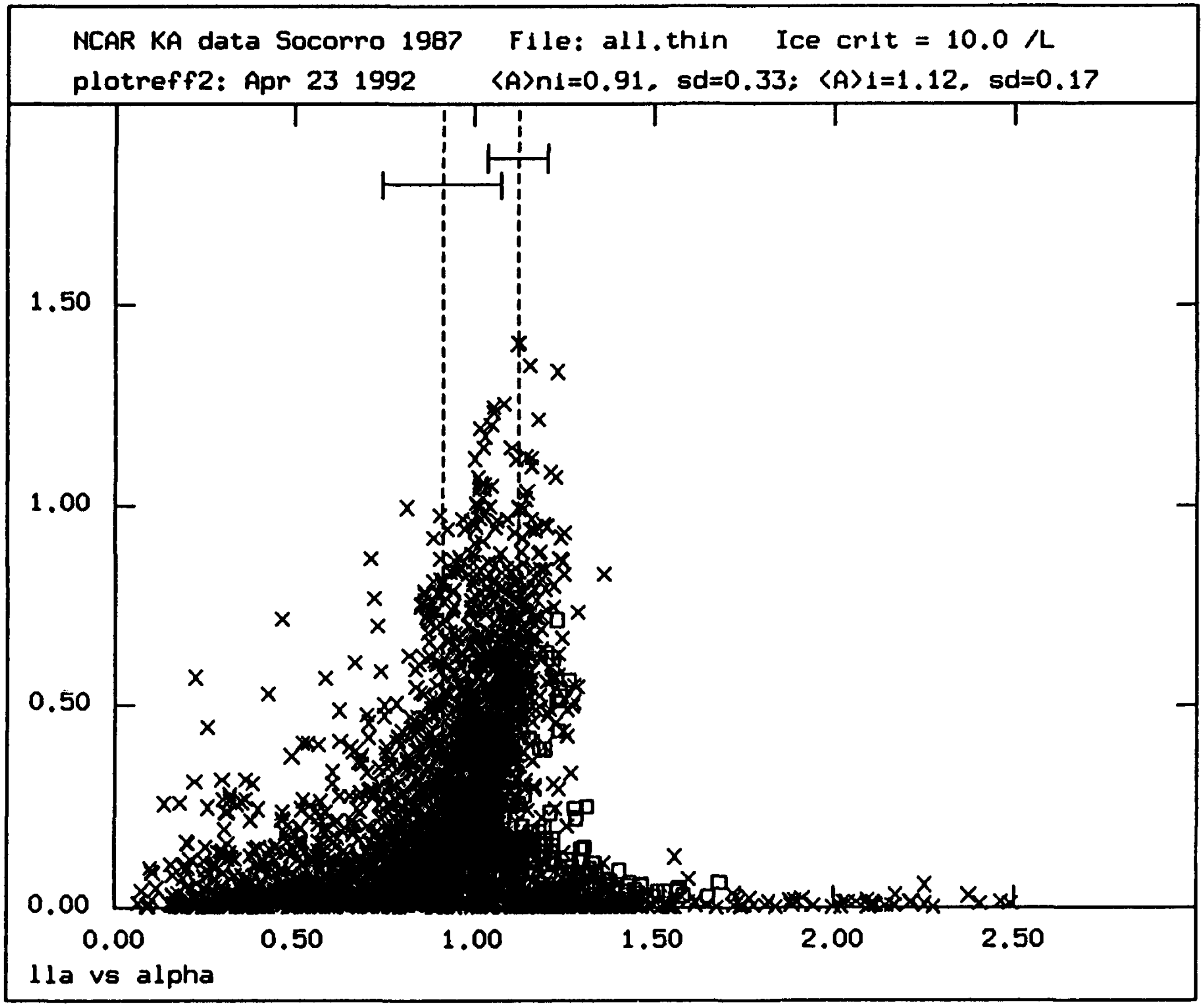
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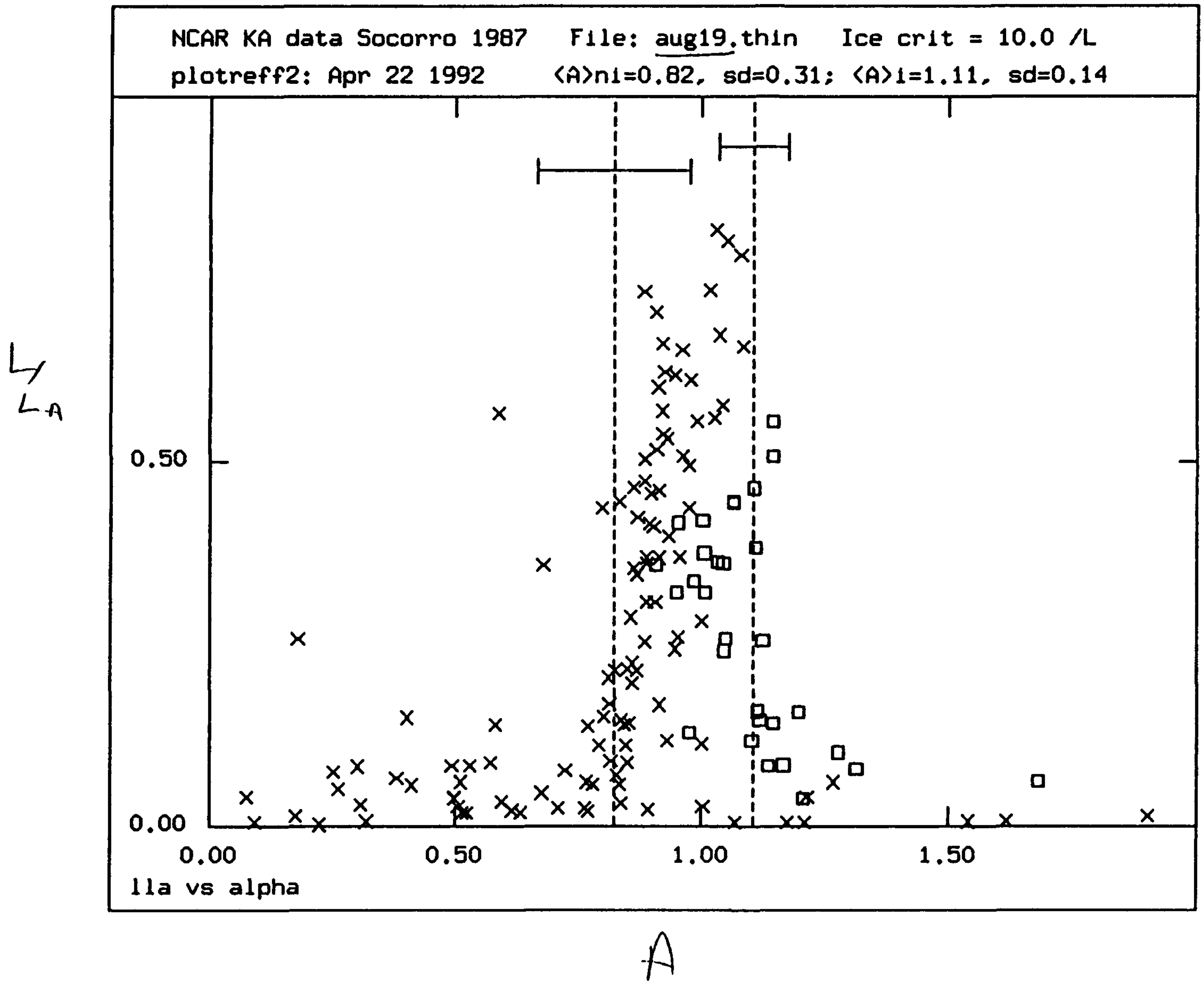

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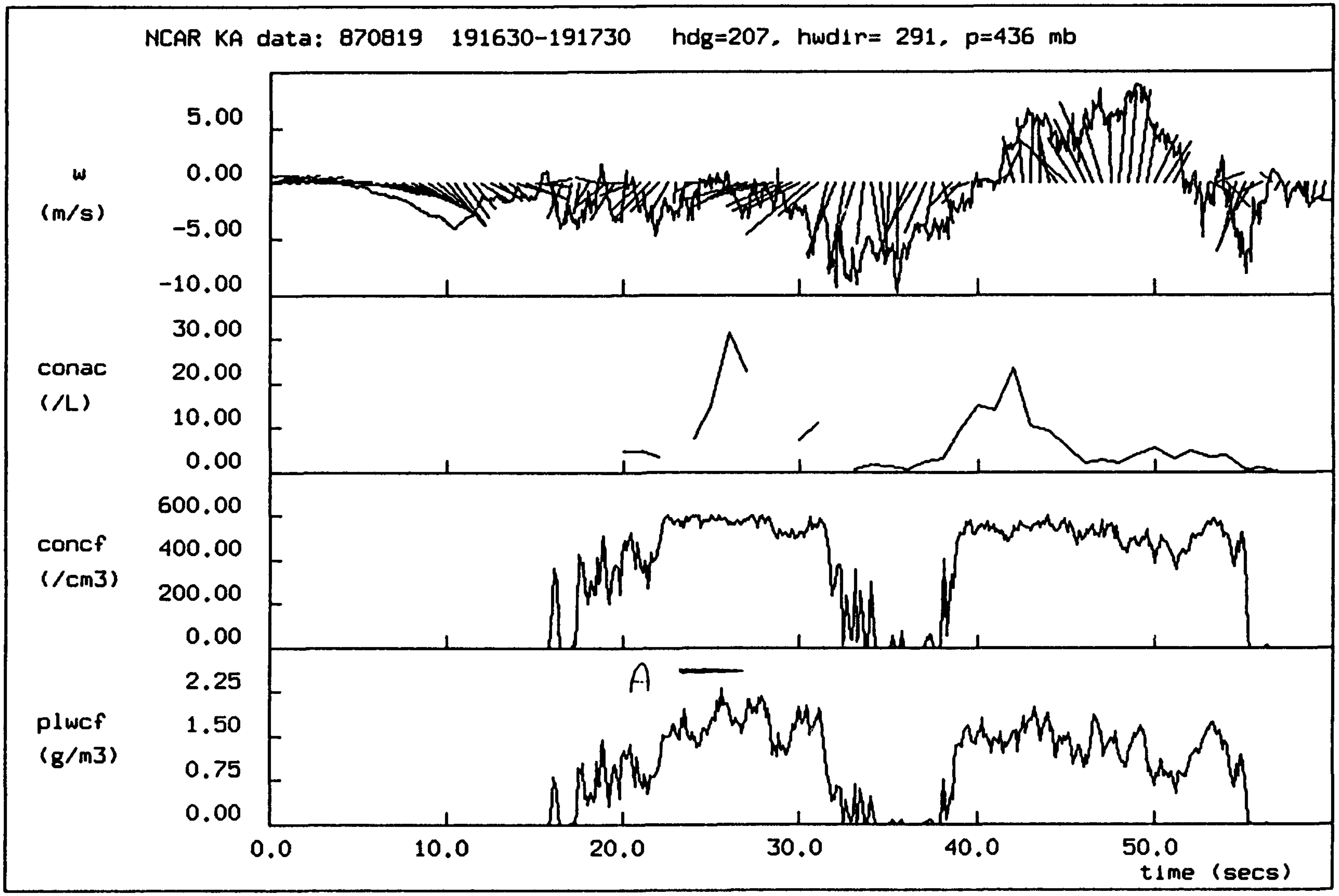
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600.00
400.00
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plwcf
(g/m3)
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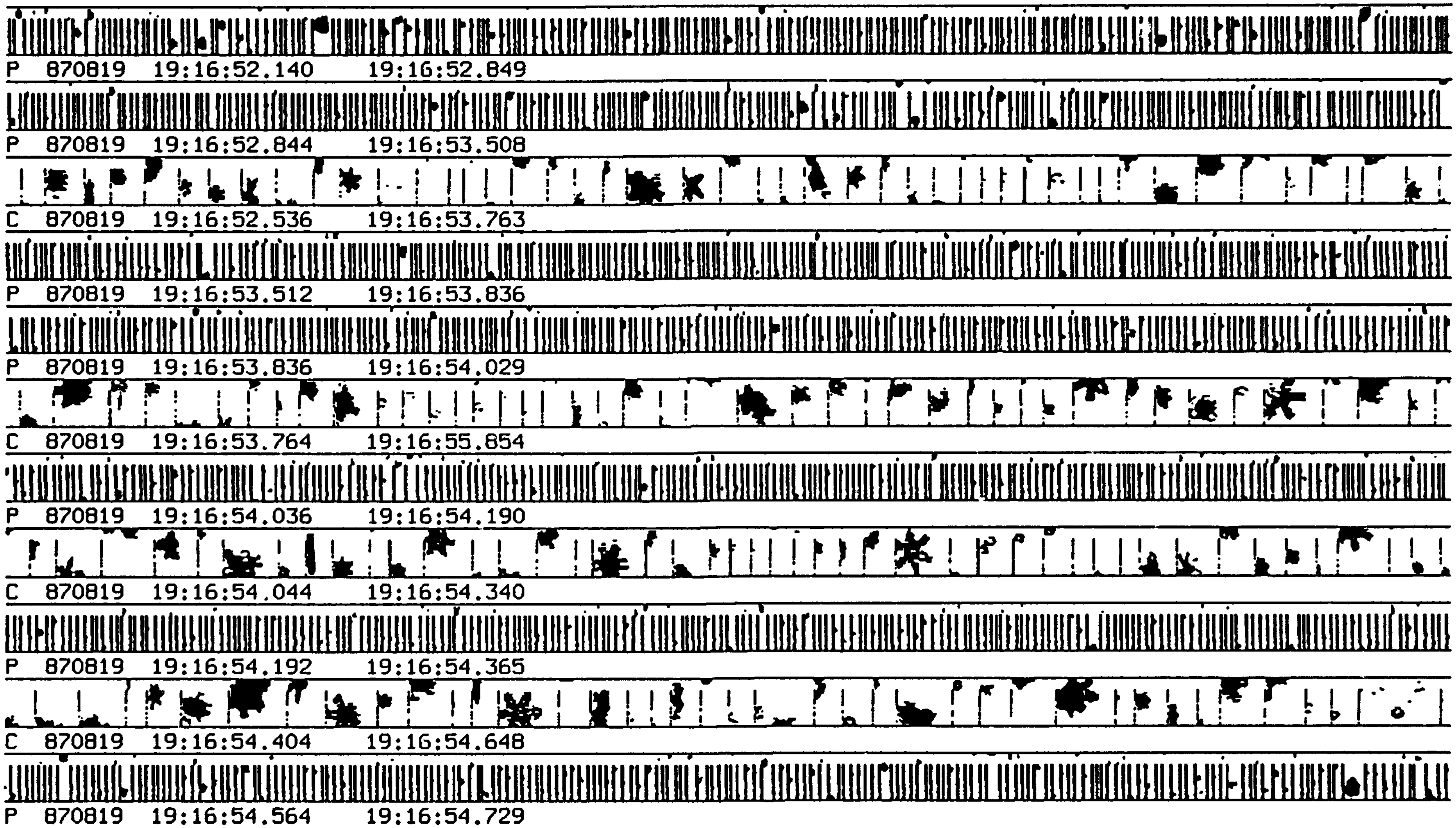
time (secs)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P 870819 19:16:53.836 19:16:54.029
C 870819 19:16:53.764 19:16:55.854
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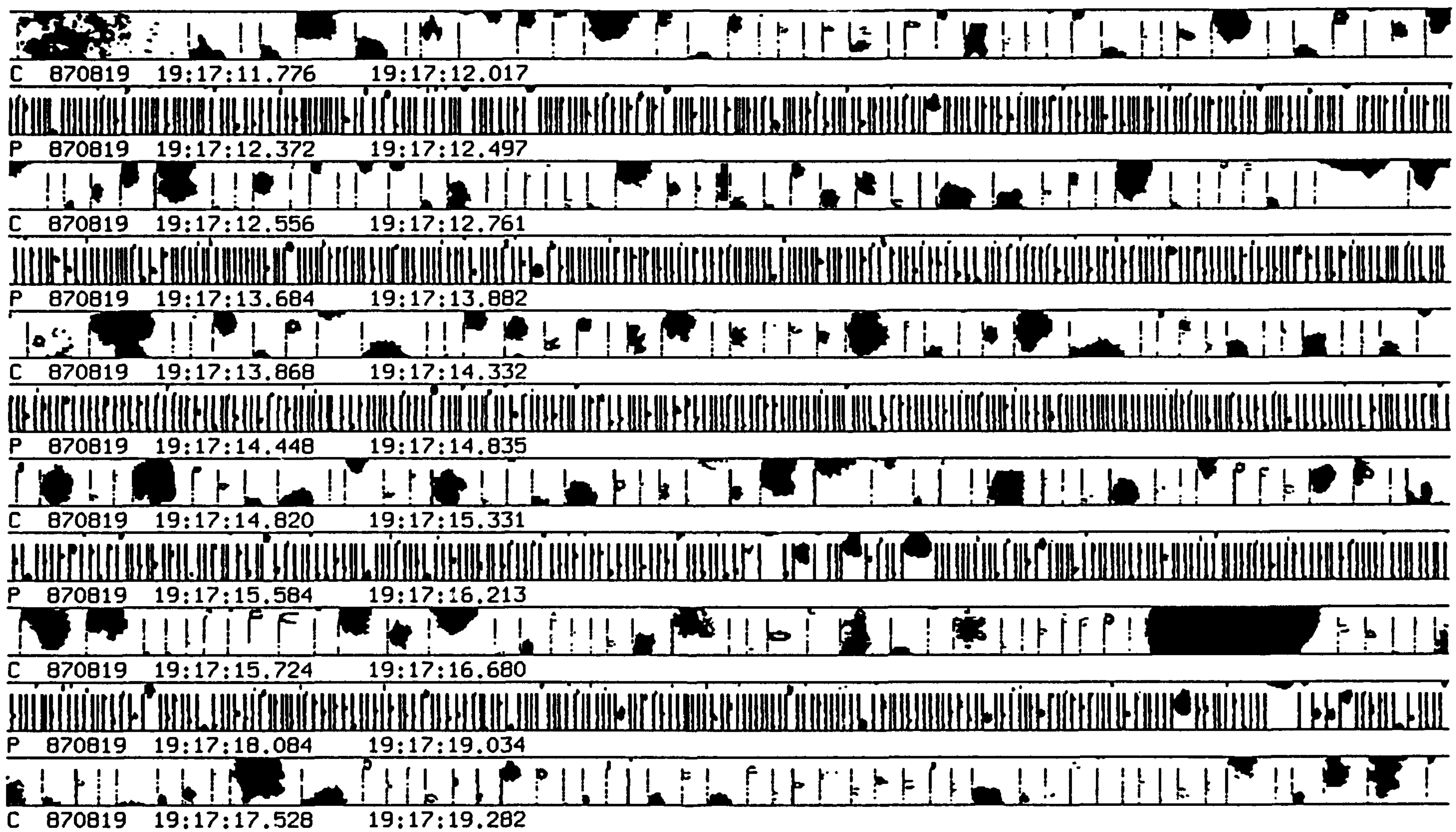
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P 870819 19:17:14.448 19:17:14.835
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SECTION 3. LABORATORY RESEARCH ON LIGHTNING

LIGHTNING INITIATION IN THUNDERCLOUDS

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Macroscopic electric fields in excess of about 400kV/m probably do not exist in thunderclouds (1). The only two mechanisms which appear capable, in such fields, of producing corona - initiatory to lightning - involve protuberances on hydrometeors of precipitation dimensions; individual ice particles (2), or pairs of colliding warm raindrops (3).

Thus the threshold field Ec for corona emission depends upon the characteristics of the hydrometeors, and breakdown will not necessarily occur in a thundercloud in the region of highest field: which has hitherto been assumed in modelling studies.

The objectives of our laboratory work were to: (a) extend the range of conditions over which Ec values are known for colliding raindrops; (b) perform similar experiments for supercooled raindrops; (c) measure Ec values associated with the collisions of supercooled drops with ice particles. In addition, data from airborne studies of thunderstorms in New Mexico was examined to establish the salient hydrometeor characteristics in regions of strong field. Figures (1) and (2) illustrate the presence of both supercooled raindrops and ice particles large enough to produce corona in fields below about 400kV/m.

The laboratory experiments (a) and (b) involved the same apparatus and procedures as described in (3). The experiments (c) utilised basically the same set-up as that described in (2), with the addition that drops fell through a hole in the upper electrode and collided with artificially produced snowflakes or hailstones mechanically suspended in a vertical electric field. The velocities of impact in these experiments were consistent with those that obtain in thunderstorms.

Figures 3,4 and 5 present data obtained in experiments (a), (b) and (c). In each case, histograms are plotted of the measured probability of corona emission as a function of the electric field E. It is seen that for all three types of interaction a significant probability exists of corona initiation in fields below 400kV/m. Photographs showed that glancing collisions produced ephemeral liquid filaments generally longer than the hydrometeor dimensions, drawn out at a shallow angle to E. Since the electrical relaxation time is substantially less than the lifetime of these conducting filaments (around 1ms) the observed corona was almost certainly emitted from their tips.

Figure 6 shows that for a constant impact parameter, the threshold field Ec for a 50% probability of corona emission was lowest at an intermediate value of impact velocity V.

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Acknowledgements

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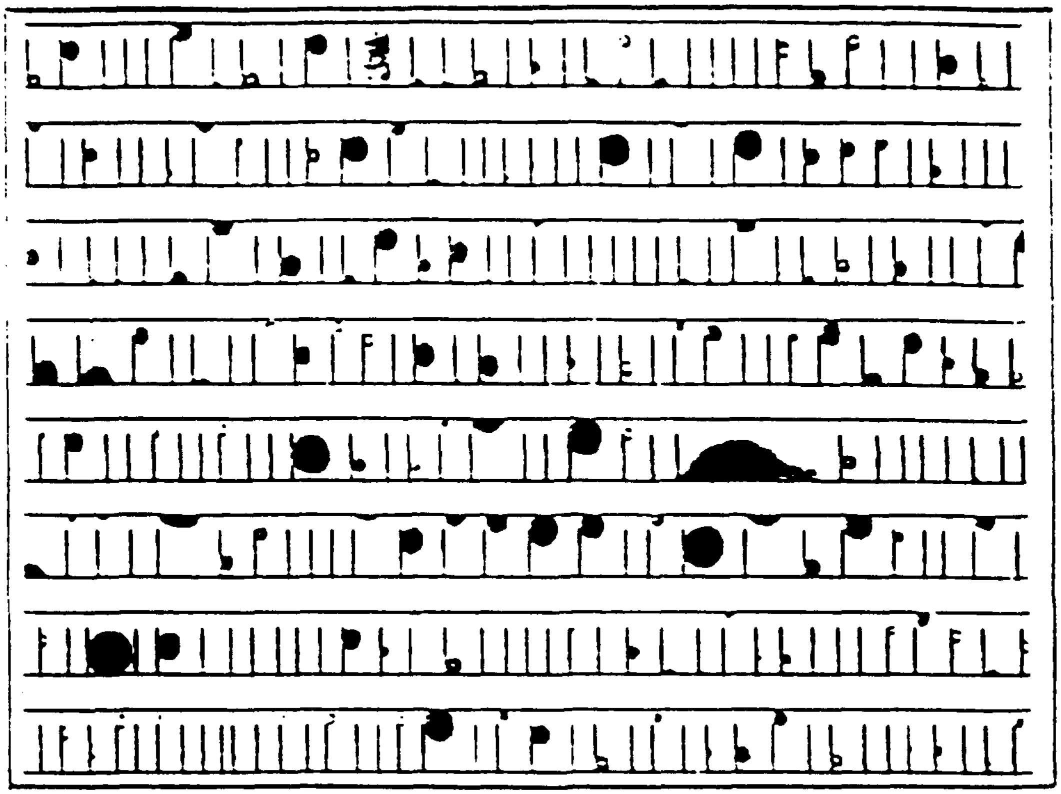
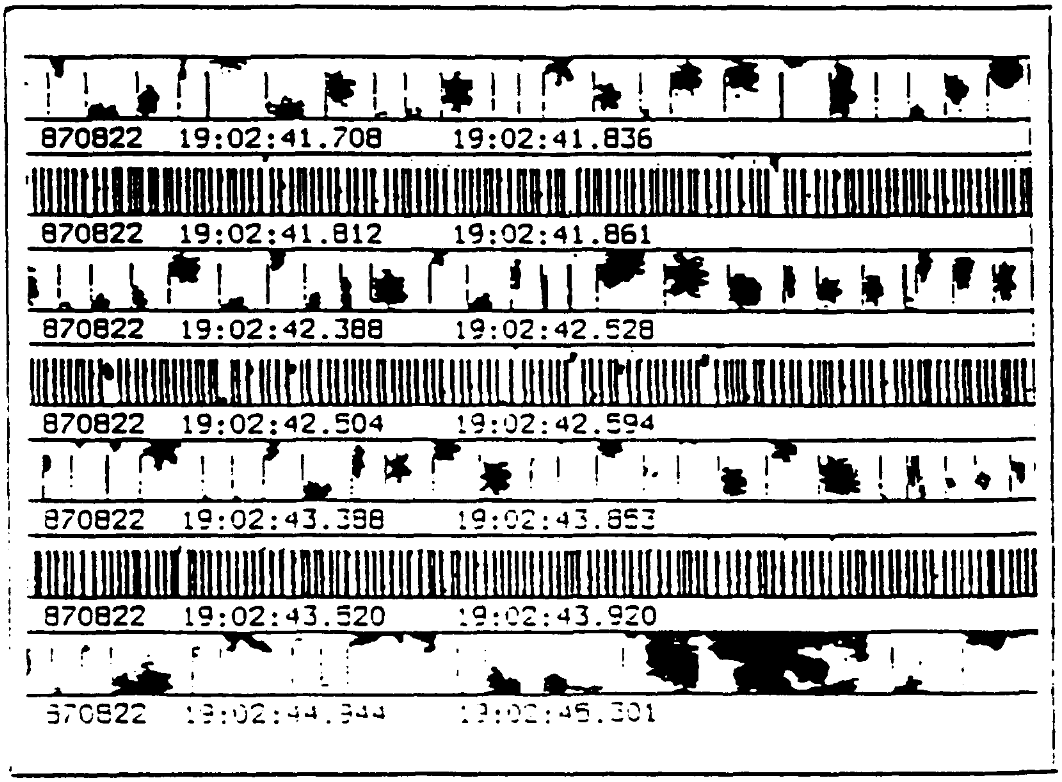


Figure 1 (1 = 0.8 mm)

Figure 2 (1 = 0.8 mm)



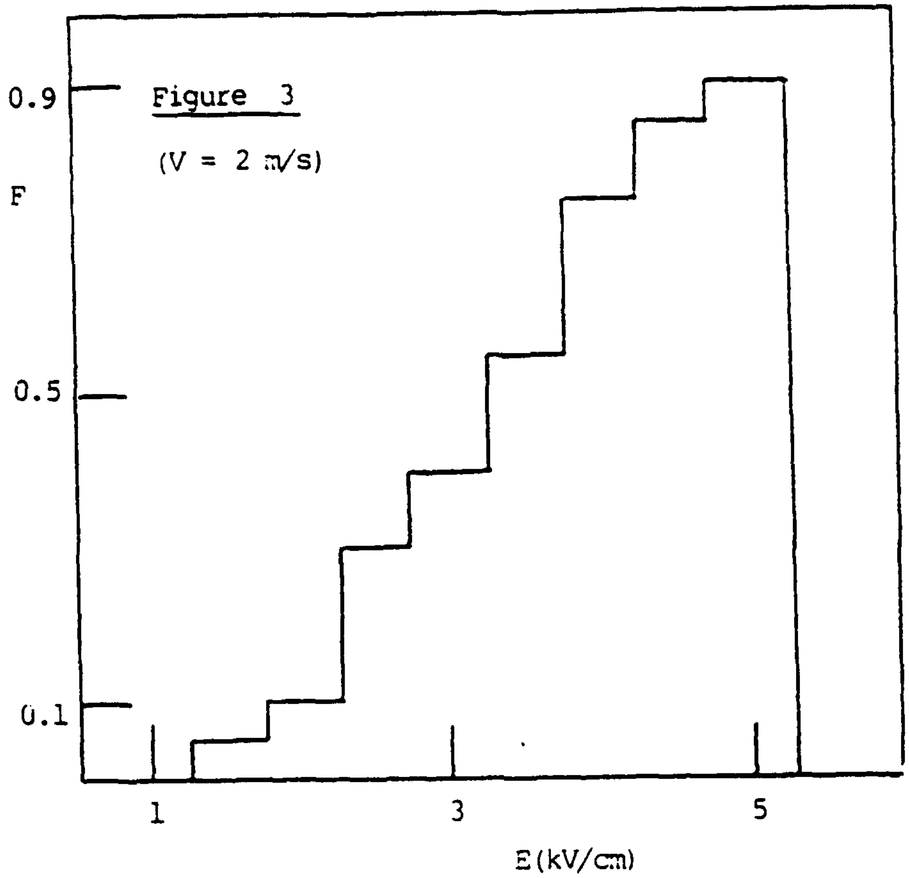

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Figure 3
(V = 2 m/s)
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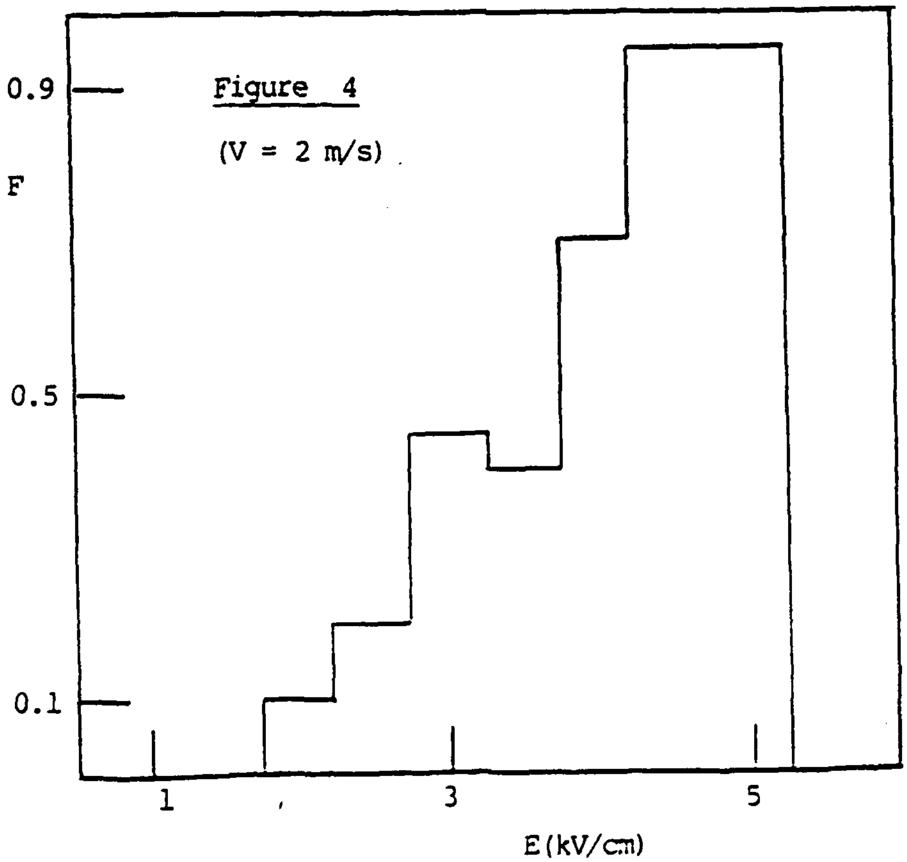
3
5
E(kV/cm)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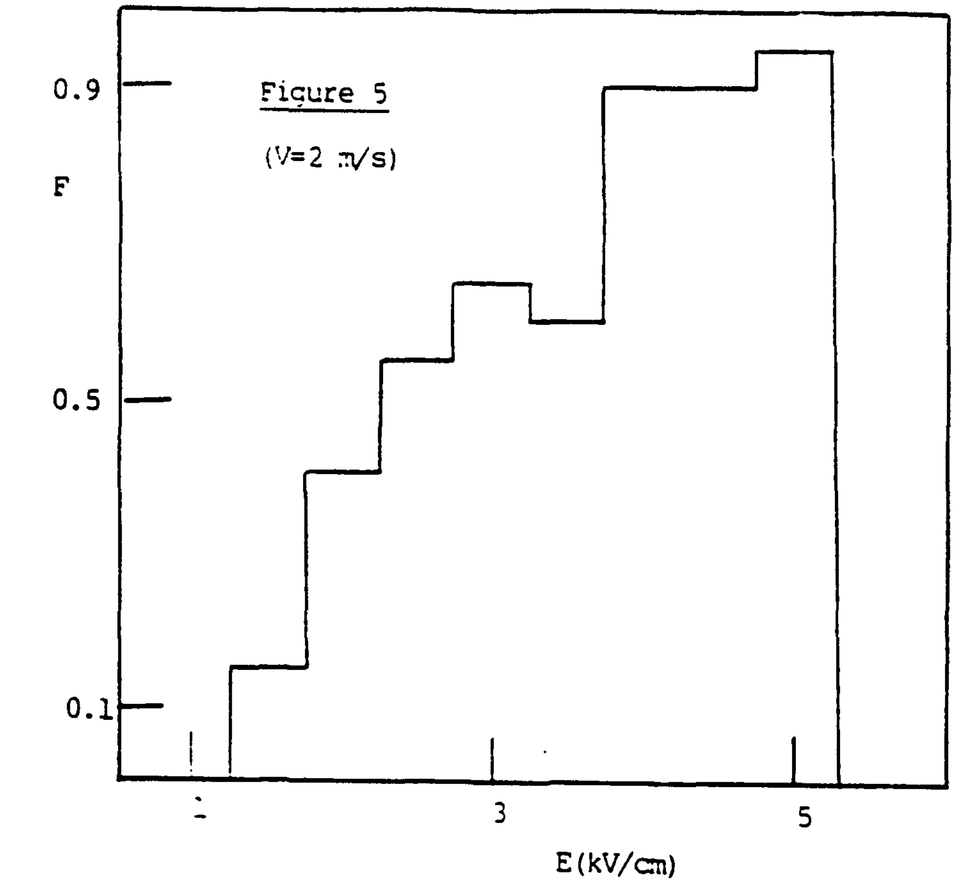


Figure 5

(V=2 m/s)

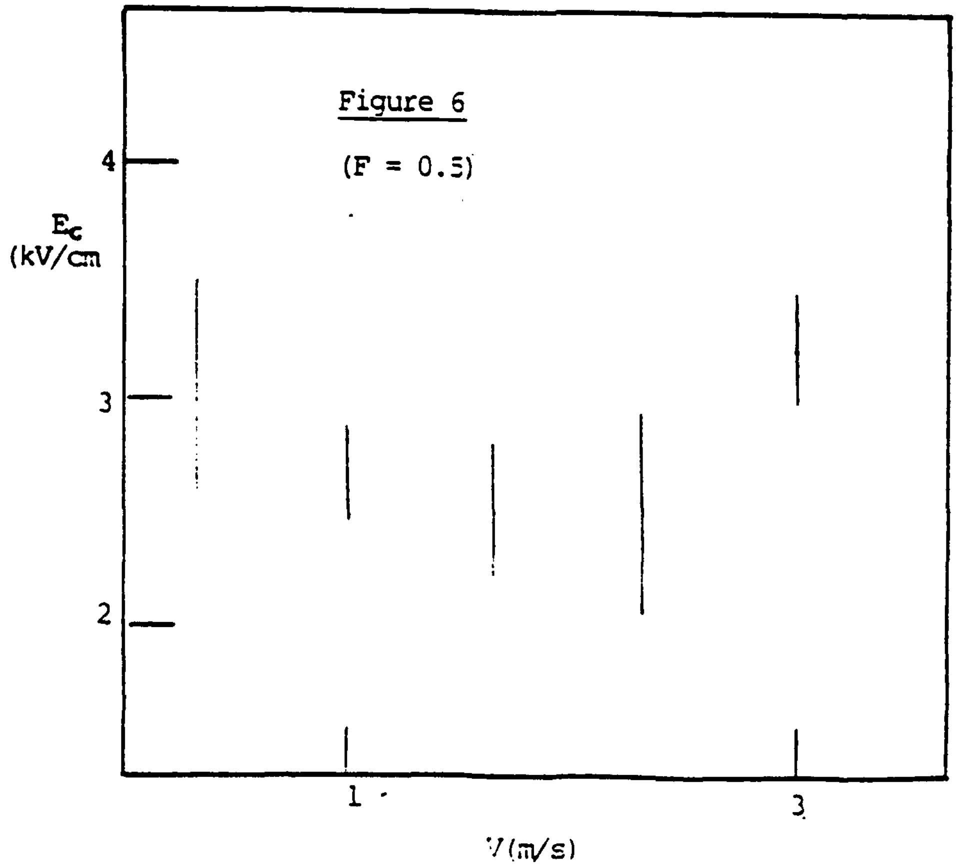


Figure 6

(F = 0.5)

SECTION 4. A NEW MODEL OF THUNDERCLOUD ELECTRIFICATION AND LIGHTNING PRODUCTION

The model exists in a variety of closely related forms, a representative version of which is described in the following paragraphs.

An updraught of specified constant speed U and width W is moving continuously through an environment whose meteorological sounding is prescribed and remains fixed throughout the period covered by each cloud simulation experiment. This ascent creates a cylindrical cloud of width W, with its axis vertical, whose base is at a pressure, altitude and temperature pb, zb and tb (>0C) respectively.

Above zb the cloud contains droplets (corresponding to a liquid-water-content L, released by condensation), and (once the cloudy air has risen above the 0C isotherm) ice crystals of number concentration nx and size dx. These solid and liquid particles ascend with speed U. The variation of L with altitude z is prescribed, its sub-adiabaticity representing depletion resulting from entrainment and vapour transfer to the ice phase. The growth of the ice crystals in the ascending air is calculated from the classical diffusion equation, with a form factor F designed to represent the asphericity of the crystals.

The ice crystals originate in two ways, which can be considered to operate in isolation or conjunction:-

A. Primary Nucleation. Following the original work of Fletcher ice crystals are assumed to be formed on nuclei existing within the cloud (either in the air or in or on supercooled droplets), their number concentration nx increasing exponentially as the temperature falls. Thus at any level above the 0C isotherm there will exist ice crystals of a range of sizes, the smallest and most numerous having just been nucleated.

B. Secondary Nucleation. This process is based on the laboratory experiments of Hallett and Mossop, in which it was discovered that within a restricted temperature band (-3 to -8C) the freezing of supercooled water droplets accreted onto the surfaces of growing graupel or hail particles may be accompanied by the ejection of ice splinters. In our model, hailstones (discussed later) falling through this temperature band sweep out supercooled water and thereby generate ice crystals (at a rate derived from the laboratory experiments) which grow as they are swept upwards through the cloud. In this simplest possible description of the Hallett-Mossop process the ice crystal concentration nx (in the absence of primary nucleation) is zero below the -3C isotherm, increases as the temperature falls to -8C, and remains constant at the -8C value at all lower temperatures. Provision exists within the model for taking account of further processes (including the possible role of supercooled raindrops in producing additional ice splinters and expediting rimer formation as they freeze) which enhance the rate of production of ice crystals. In treating this refinement to the basic Hallett-Mossop process use is made of the analytic treatment of Chisnell and Latham, which showed that this further enhancement of nx can be represented by a simple exponential relationship.

At some level pi, zi, Ti the cloud is inocculated at a specified rate F per unit area with embryonic spherical hailstones of diameter Do and constant density rho. These grow according to the classical coalescence equation by the accretion of supercooled water which freezes onto their surfaces. The hailstones have a size-dependent terminal fall-speed V and thus rise (relative to the ground) at a speed U-V until they reach the balance level (pbal, zbal, Tbal), where U-V=0; at which point they begin to descend through cloud towards earth with a continually increasing velocity V-U. Hailstone growth is assumed to cease when the hydrometeors fall through the 0C isotherm. Thus the hailstone are continually growing throughout their period in the supercooled regions of the cloud, and are monodisperse in size at all levels (except that between the levels zi and zbal there are two sizes, one for the upward-moving particles, and one for the descending ones). Throughout their journey below the 0C isotherm, first of all through cloud and then through clear air to ground the hailstone-size is assumed to be constant.

Thus ice crystals, hailstones and supercooled water coexist within the thundercloud at all levels between zbal and the isotherms located at either 0C or -3C (according to which of the above-mentioned glaciation mechanisms is operating). This combination of hydrometeor types is required for the effective operation of the non-inductive ice-ice collisional process of charge transfer, which is generally regarded as the mechanism most likely to be of primary importance in thunderstorm electrification. Under this mechanism, which is the only charging process considered in the present computations, the charge q separated when a rebounding collision occurs between a hailstone and an ice crystal depends sensitively on the crystal size dx and the relative fall-speed V of the hydrometeors. The quantitative relationship between q, dx and V is abstracted from the laboratory experiments of Saunders and colleagues; and we adopt, from these studies, the finding that at temperatures colder than a reversal value Trev the hailstone is charged negatively by rebounding collisions with crystals, and at temperatures warmer than Trev the hailstones become positively charged. We do not take account in the present work of reports that Trev is dependent upon L.

Thus charge transfer occurs throughout the region of the thundercloud (the interaction zone) in which ice crystals, supercooled water droplets and hailstones coexist; and nowhere else. The parameters pbal, zbal and Tbal define the pressure, altitude and temperature respectively of the upper bound of the interaction zone; and this level - and thus the volume within which charging occurs - increases with increasing updraught speed U.

As gravitational separation of ice crystals and hailstones proceeds, with both types of particles present in the interaction zone, crystals (no hailstones) moving above the balance level into the cloud anvil, and hailstones (no crystals) falling through the base of the interaction zone, through cloud-base and ultimately to ground (where they are assumed to be neutralised), an electric field is developed, the axial component of which (Ez) is calculated over the entire vertical depth of the domain covered by the calculations i.e. from the ground up to cloud-top, whose altitude, temperature and pressure values (ztop, Ttop and ptop respectively) are determined from the meteorological sounding.

In most (though not all) situations the ice-crystals are predominantly positively charged, with a corresponding negative charge on the hailstones. Once air containing charged ice crystals has risen to cloud-top, subsequent charge flowing upwards through the balance level is assumed to be uniformly mixed throughout the depth of the anvil.

Under conditions of adequate charging rate the axial electric field Ez at all levels increases until, at some altitude zzap (where the corresponding pressure and temperature are pzap and Tzap) it reaches a value Ecrit at which lightning is presumed to be initiated. Ecrit is generally taken to be 300kV/M (references), and characteristically it is achieved within the interaction zone, near to its top.

Lightning originating at the level zzap may take the form of either an intra-cloud (I-C) or a cloud-to ground (C_G) stroke.

In the case of an I-C stroke we assume that a fraction E (usually 0.1) of the (generally positive) charge in the cloud anvil is abstracted uniformly from all levels and deposited uniformly in a cylindrical region of cloud of width W and depth zav (of typical value 0.5km) whose upper bound is the balance level zbal. Prior to the lightning stroke this region contains both negative and positive charge, with generally a preponderance of the former. The charge transferred (Q) is assumed to be located on the small cloud particles (ice crystals or droplets) and therefore it immediately starts to move upwards at the updraught speed U. We neglect the possibility that some of it may be deposited on or captured by hailstones. We also neglect neutralisation of positive and negative charges at the same level.

In the case of a C-G lightning stroke we assume that a charge Q (generally positive) is transferred from the ground to the above-mentioned cylindrical region of depth zav, whereupon it manifests the same behaviour and is subjected to the same restrictions as the positive charge destroyed in an I-C stroke. The magnitude Q of the charge transferred in a C-G stroke is defined by the same criterion as for I-C strokes.

To determine whether a lightning stroke occurring whenever the breakdown field Ecrit is achieved is of the I-C or C-G category, we examine the gradient of the vertical electric field Ez immediately above and below the breakdpwn level zzap at the point when Ez=Ecrit. If the gradient is smaller in the upward direction we assume that the lightning stroke is of the I-C form; whereas a C-G stroke occurs if the gradient is stronger in the downward direction. The rationale for adopting this criterion is that the corona streamers leading to lightning will grow preferentially in stronger ambient fields - from which they can derive more energy in order to facilitate their propagation.

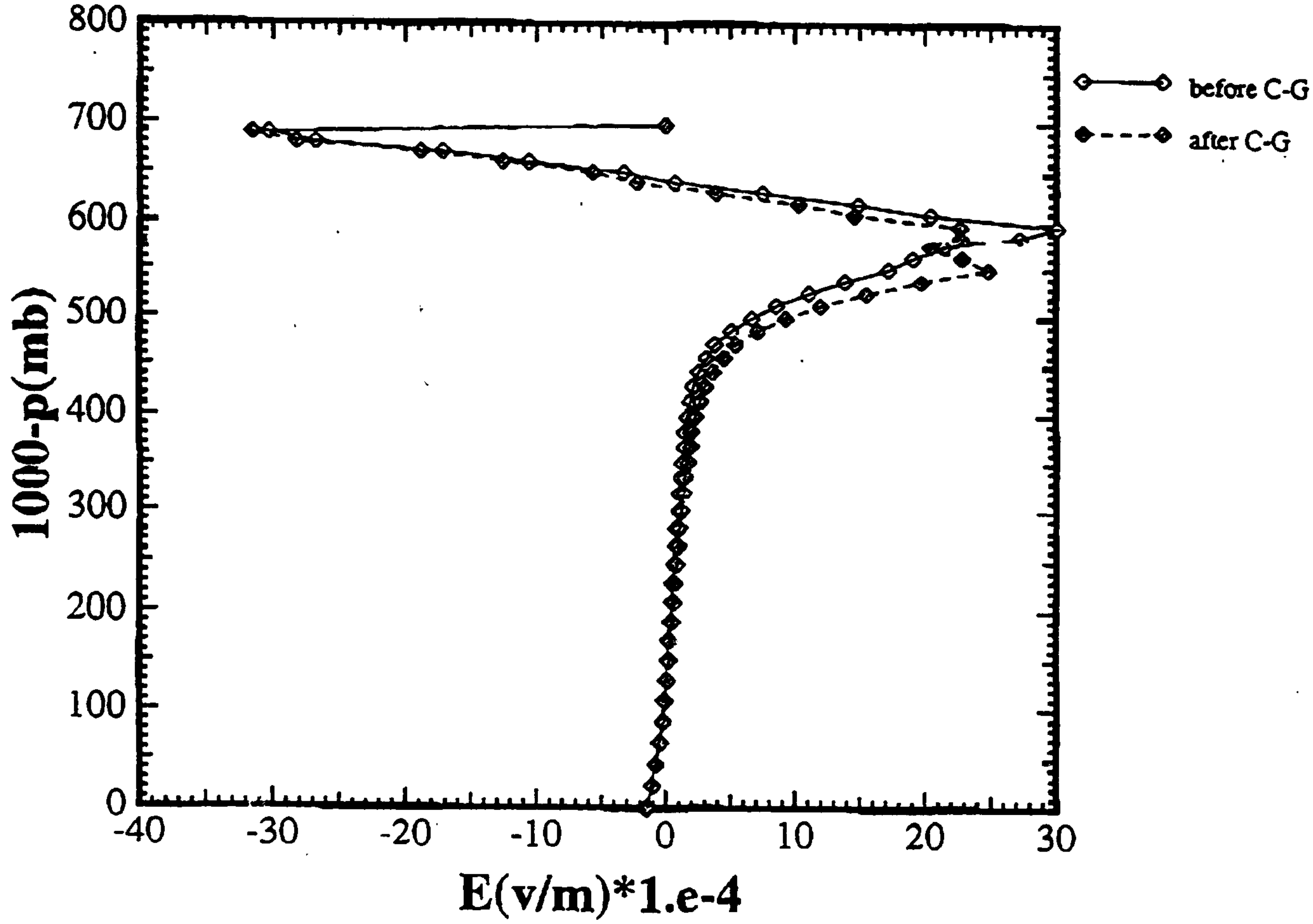
After the lightning stroke has occurred the maximum electric field in the thundercloud is diminished, but as charging via the non-inductive process continues Ez will increase until the value Ecrit is again achieved, and a second lightning stroke occurs. This pattern is reproduced throughout the period of the computations.

In this way, calculations are made of: times of occurrence of lightning strokes (t1, t2, t3, etc); charge transferred in each one (Q); the altitudinal variation, throughout the computational period, of axial electric field (Ez), positive charge density (Q+), negative charge density (Q-), precipitation current (Ip), radar reflectivity (Z), precipitation rate (p), hailstone size (D), the number concentration (Nx) and sizes (dx) of ice crystals; and the location (pbal, zbal, Tbal) of the balance level. The above-mentioned parameters are calculated for a specified sounding, altitudinal variation of liquid-water-content (L) and glaciation mechanism; and prescribed values of updraught speed U, cloud width W, hailstone flux F and other parameters defined earlier.

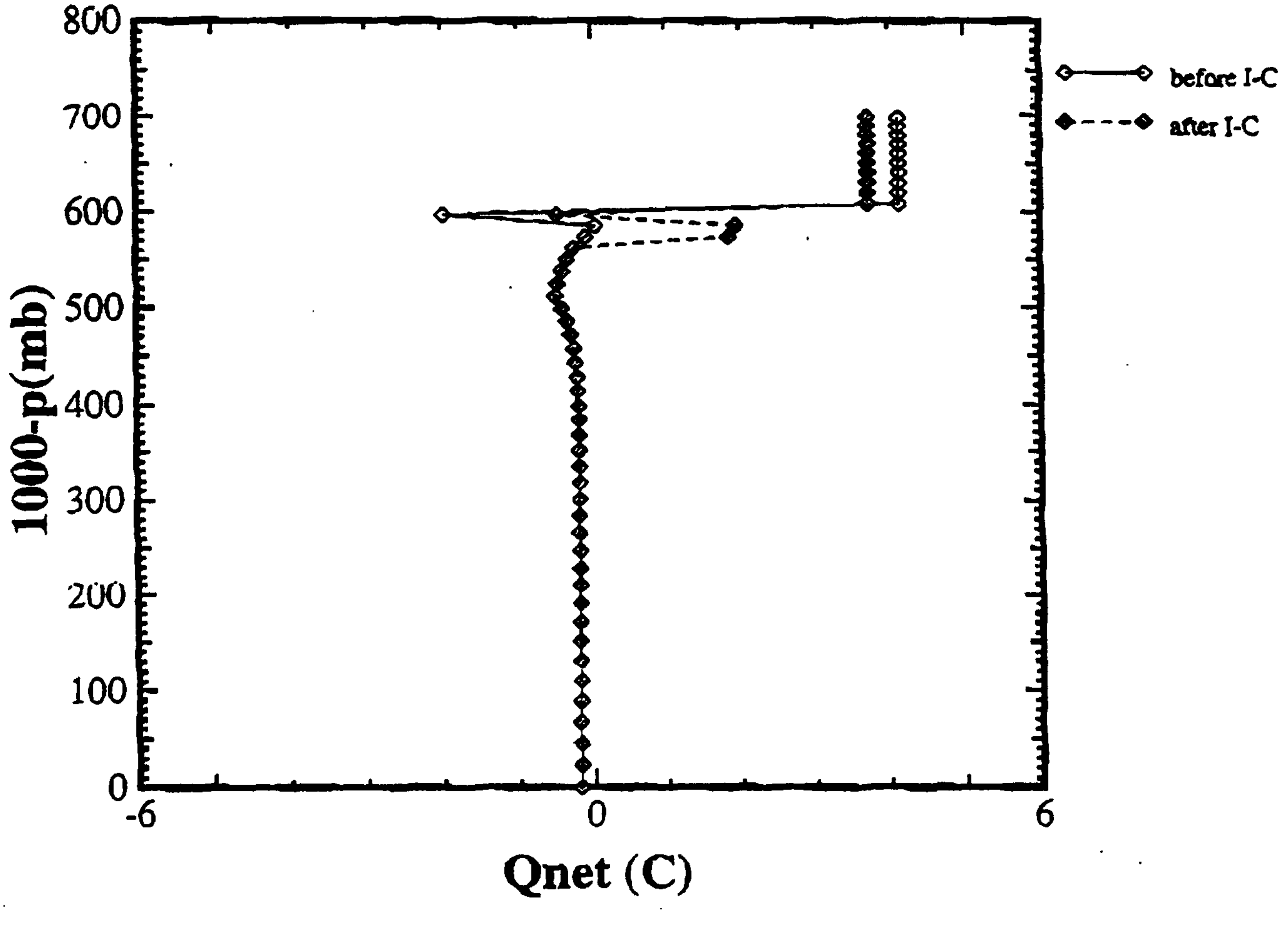
In the following nine pages we present a set of figures illustrating particular results emanating from our model, which we stress is still in a preliminary form. They show vertical field and charge profiles just before and just after breakdown, for both cloud-to-ground and inter-cloud lightning strokes; the sensitivity of predicted lightning frequency to cloud width, ice crystal concentration and (especially) updraught speed; and the close parallelism found between 1/f and the time of first occurence of lightning.

This report concludes with a specimen set of output, from which it is possible to assess in detail the influence on lightning activity of parameters defined earlier in this section.

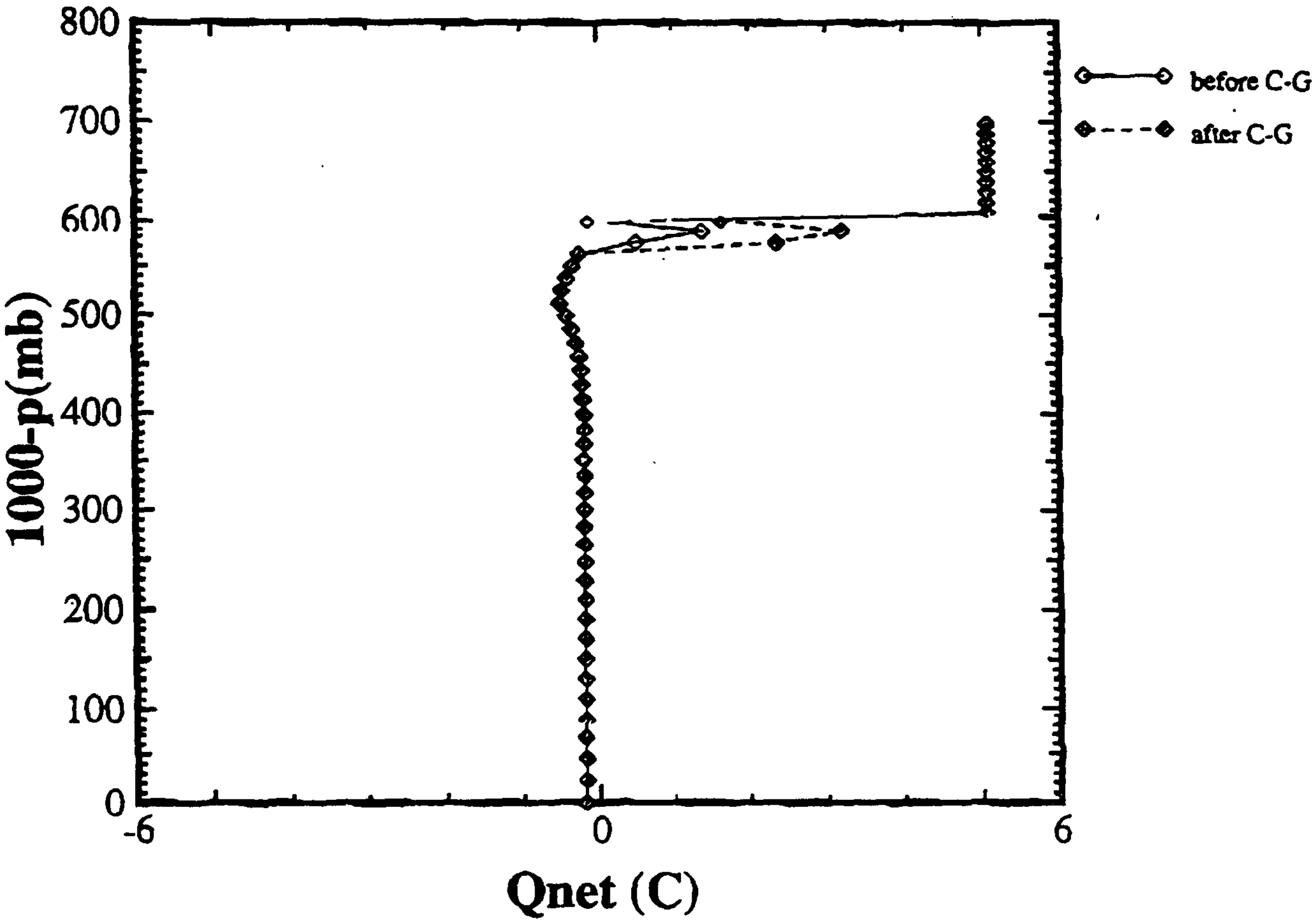
Field Change: C-G Stroke



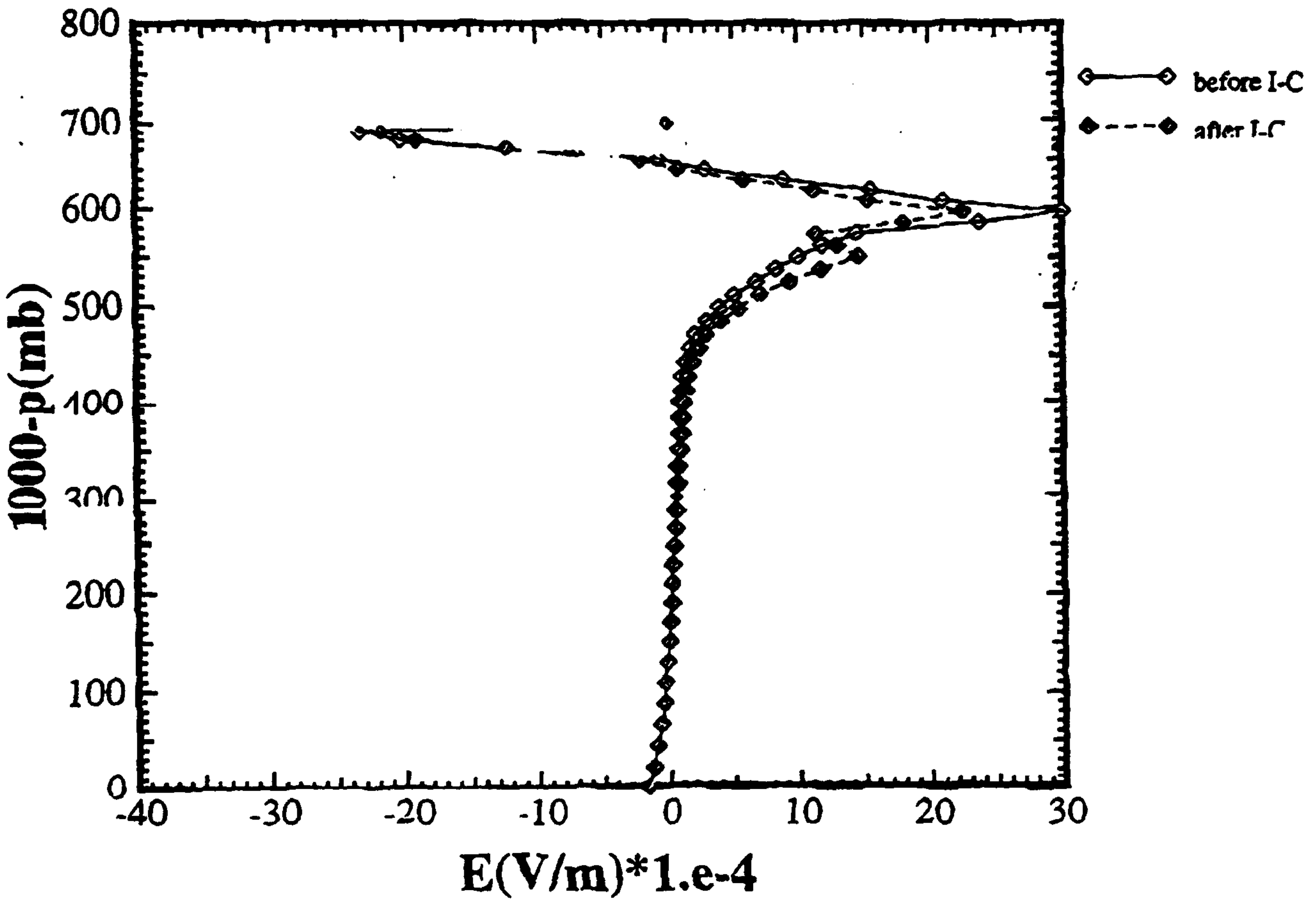
Charge Distribution Change: I-C Stroke



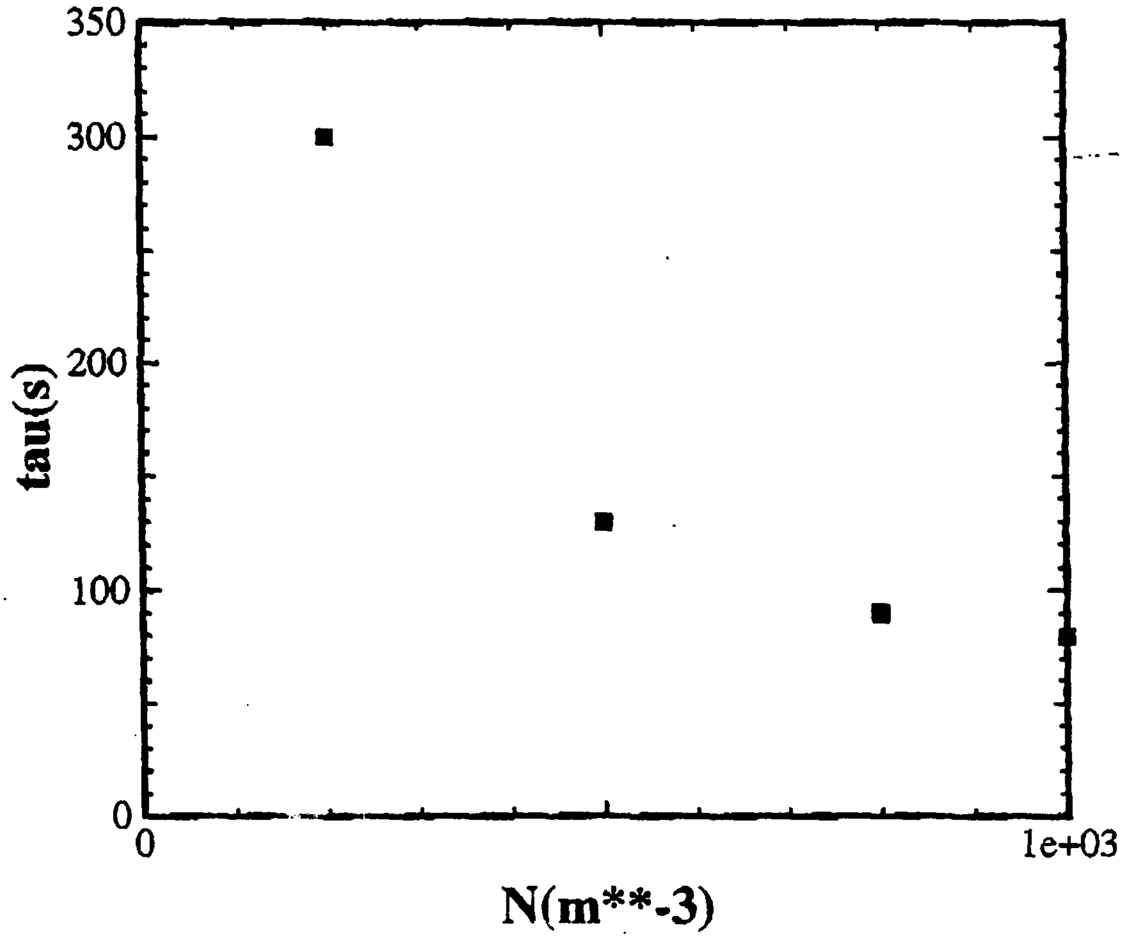
Charge Distribution Change: C-G Stroke



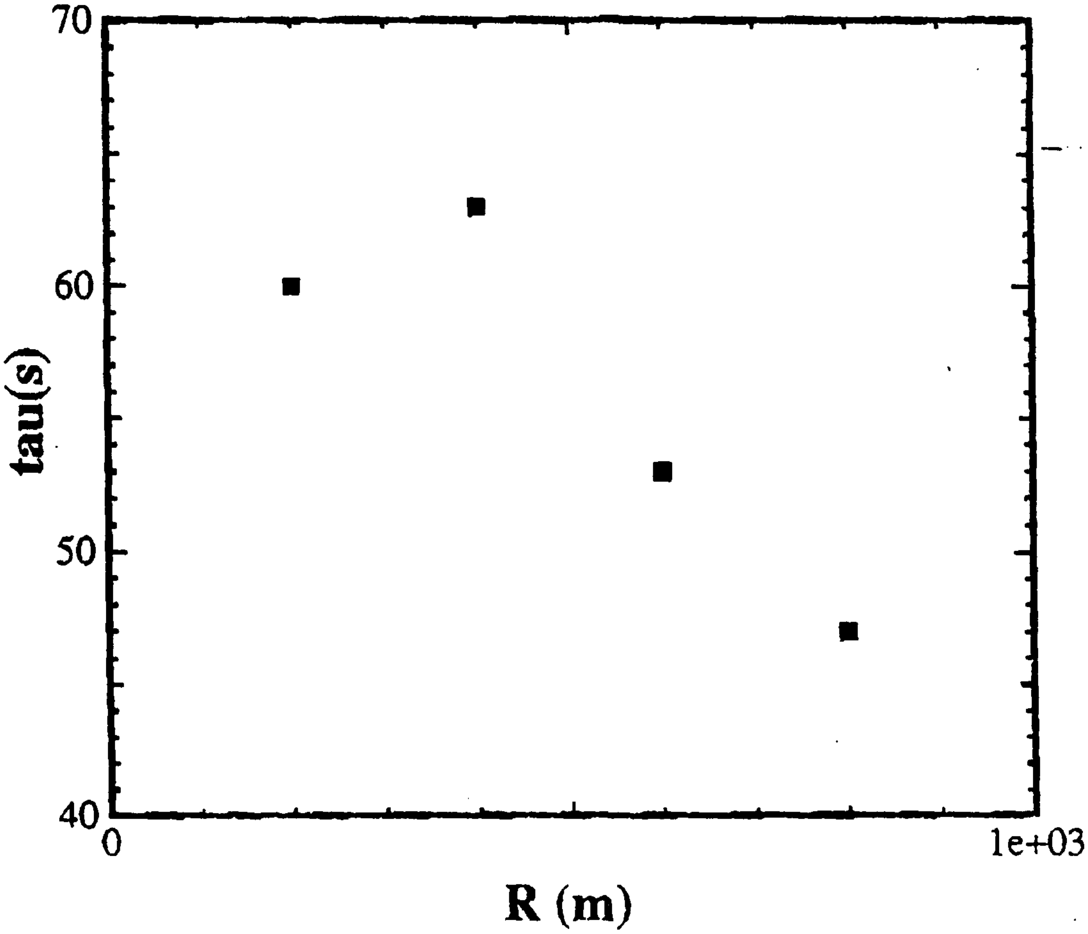
Field Change: I-C Stroke

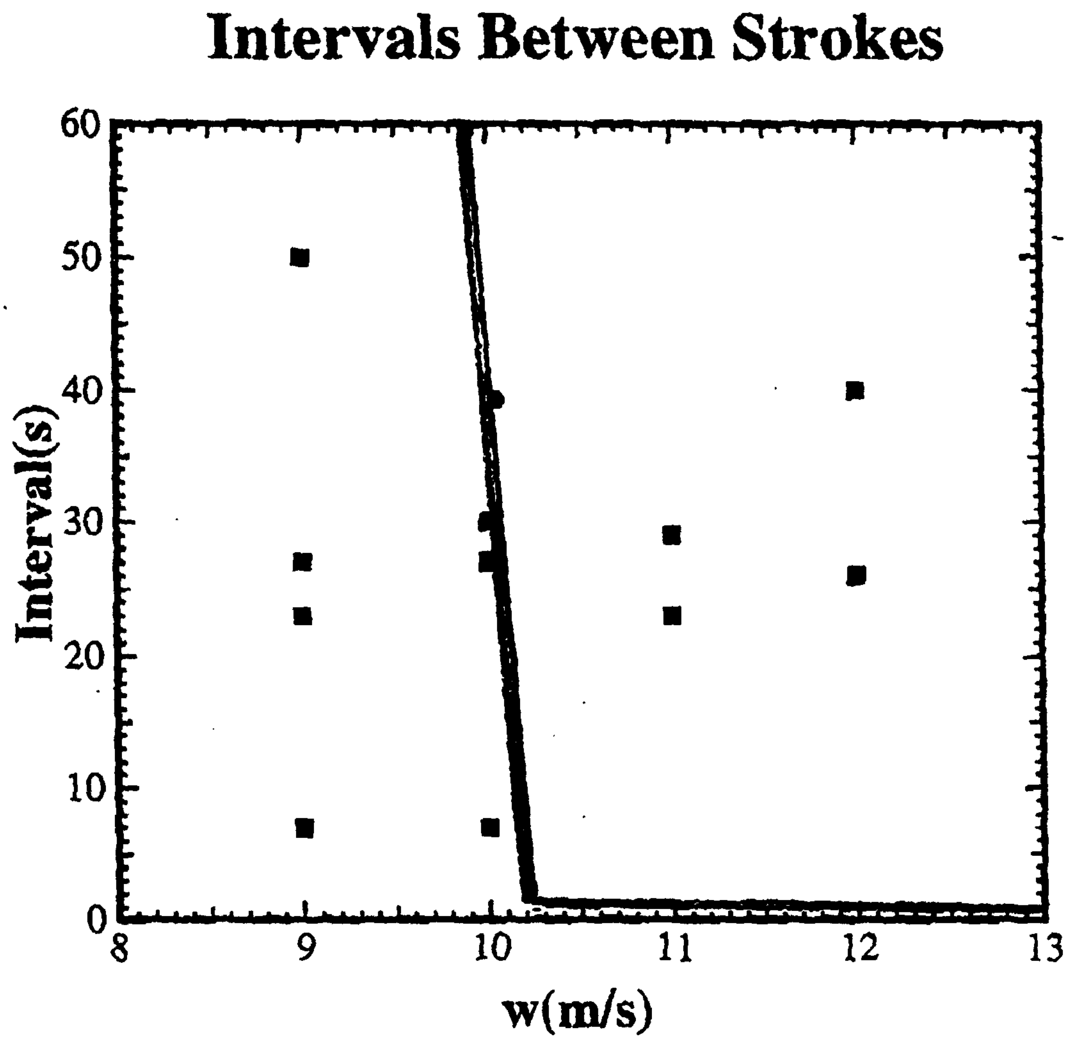


R=1000m: w=10m/s: Fletcher Run

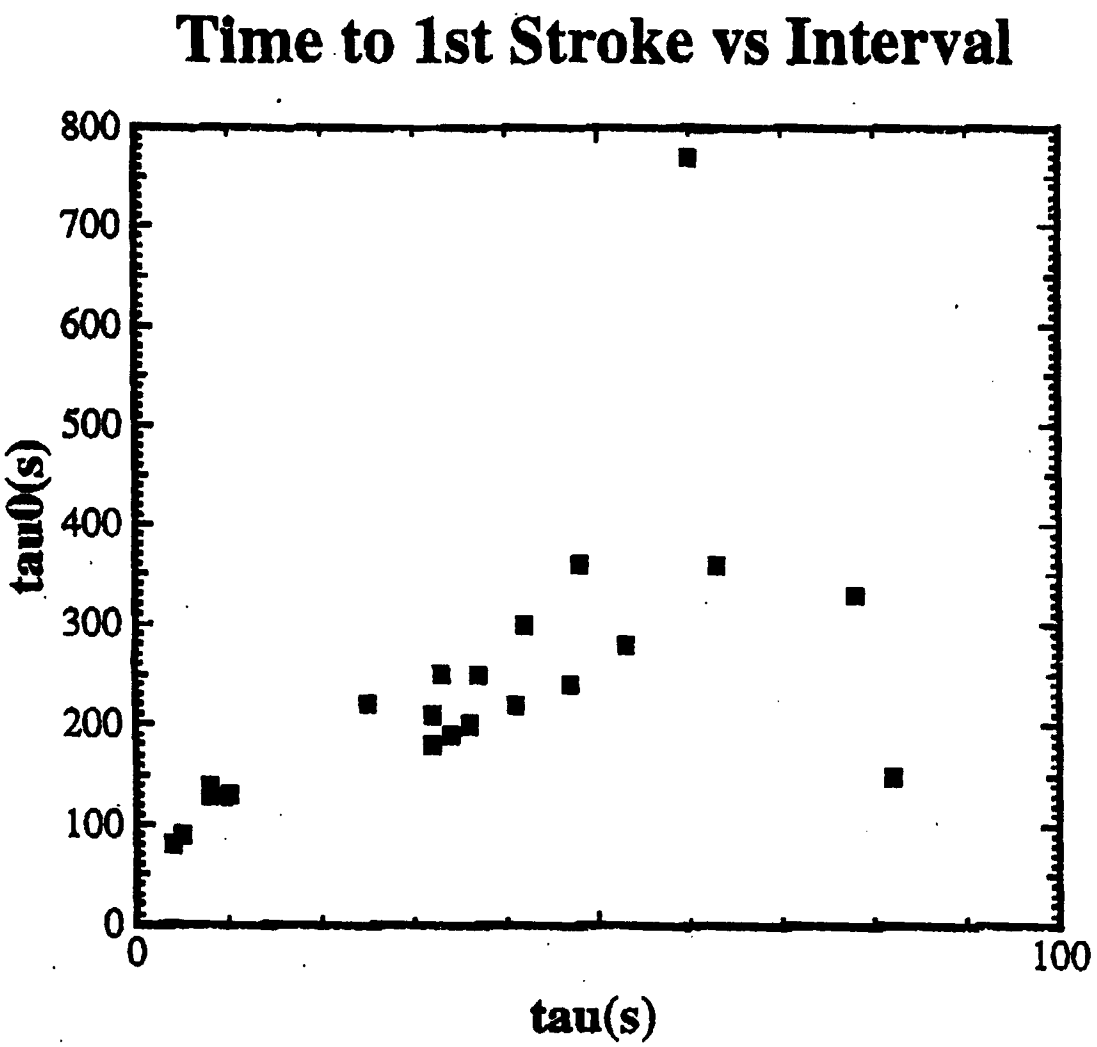


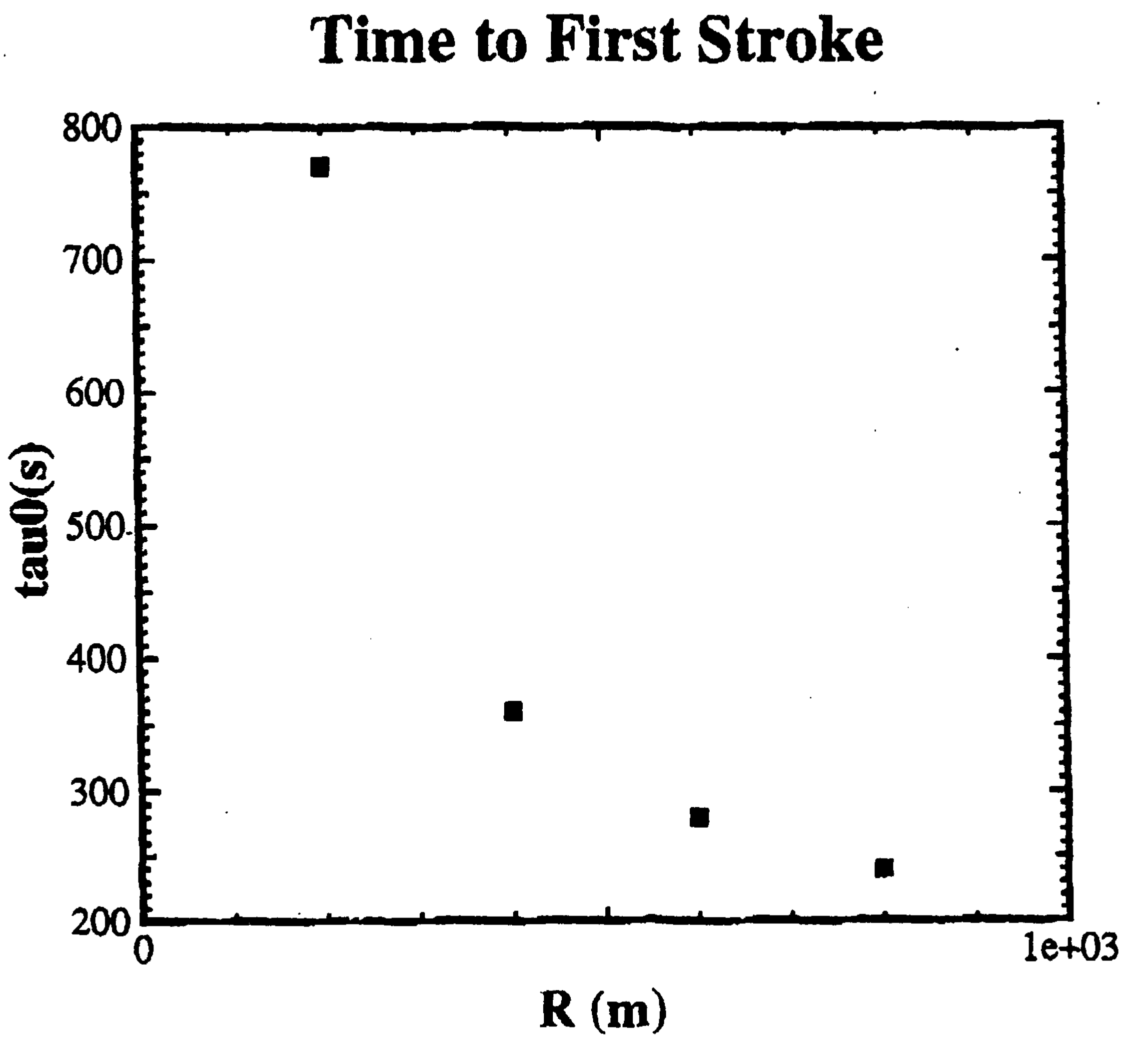
Intervals vs Cell Radius





Intervals Between Strokes
Interval(s)
w(m/s)
60
50
40
30
20
10
0
8
9
10
11
12
13


Time to 1st Stroke vs Interval
800
700
600
500
400
300
200
100
0
0
100
tau0(s)
tau(s)


Time to First Stroke
800
700
600
500
400
300
200
tau0(s)
0
1e+03
R (m)

Fletcher Glaciation Run
Fletcher x 200.
Cell Radius = 1000.0 m.
updraft speed = 10.0 m/s
freezing level= 616.8 mb: balance level= 403.2mb
time step= 10.0s
Hailstone Flux = 0.500E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse= 258.0 K. Ql= 0.120E-02 kg m**-3
charge destroyed is 0.10 times that in a layer 1800.0
meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.344E-02

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
300.0	403.2	300.0	1.39	(I-C)	1.17
694.0	403.2	394.0	3.24	(I-C)	1.17
747.0	403.2	53.0	3.46	(I-C)	1.60
789.0	403.2	42.0	3.62	(I-C)	1.92
825.0	403.2	36.0	3.76	(I-C)	2.22
857.0	403.2	32.0	3.87	(I-C)	2.49
887.0	403.2	30.0	3.98	(I-C)	2.71
915.0	403.2	28.0	4.08	(I-C)	2.93
942.0	403.2	27.0	4.17	(I-C)	3.11
967.0	403.2	25.0	4.25	(I-C)	3.34

Calculation stopped at time= 991.0 seconds.
Total number of lightning strokes = 11

Precipitation reaches the ground at 428.0 s.
Current to ground= 0.859E+07fC/m**2/s
Rain intensity at the ground= 2.10 mm/hr

pressure	radar	P(mm/hr)
617.	56.8	0.679
601.	56.6	0.651
586.	56.4	0.623
571.	56.2	0.596
557.	56.0	0.570
543.	55.8	0.544
529.	55.6	0.518
515.	55.5	0.492
501.	55.3	0.467
488.	55.1	0.442
475.	54.9	0.417
463.	54.8	0.392
450.	54.7	0.367
438.	54.6	0.341

426.	54.5	0.314
415.	55.1	0.251
403.	60.8	0.464E-01

Fletcher Glaciation Run
Fletcher x 800.
Cell Radius = 1000.0 m.
updraft speed = 10.0 m/s
freezing level= 616.8 mb: balance level= 403.2mb
time step= 10.0s
Hailstone Flux = 0.500E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse= 258.0 K. Ql= 0.120E-02 kg m**-3
charge destroyed is 0.10 times that in a layer 1800.0 meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.137E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
90.0	403.2	90.0	1.61	(I-C)	1.14
94.0	403.2	4.0	1.63	(I-C)	1.31
100.0	403.2	6.0	1.69	(I-C)	1.45
105.0	403.2	5.0	1.74	(I-C)	1.58
110.0	403.2	5.0	1.79	(I-C)	1.69
115.0	403.2	5.0	1.85	(I-C)	1.79
120.0	403.2	5.0	1.91	(I-C)	1.89
124.0	403.2	4.0	1.94	(I-C)	1.99
129.0	403.2	5.0	2.01	(I-C)	2.06
133.0	403.2	4.0	2.04	(I-C)	2.15

Calculation stopped at time= 138.0 seconds.
Total number of lightning strokes = 11

pressure	radar	P(mm/hr)
543.	54.0	0.354
529.	55.6	0.518
515.	55.5	0.492
501.	55.3	0.467
488.	55.1	0.442
475.	54.9	0.417
463.	54.8	0.392
450.	54.7	0.367
438.	54.6	0.341
426.	54.5	0.314
415.	55.1	0.251
403.	60.8	0.464E-01

Fletcher Glaciation Run
Fletcher x 500.
Cell Radius = 1000.0 m.
updraft speed = 10.0 m/s
freezing level= 616.8 mb: balance level= 403.2mb
time step= 10.0s
Hailstone Flux = 0.500E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse= 258.0 K. Ql= 0.120E-02 kg m**-3
charge destroyed is 0.10 times that in a layer 1800.0

meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.859E-02

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
130.0	403.2	130.0	1.47	(I-C)	1.15
139.0	403.2	9.0	1.53	(I-C)	1.41
149.0	403.2	10.0	1.61	(I-C)	1.60
159.0	403.2	10.0	1.70	(I-C)	1.76
168.0	403.2	9.0	1.78	(I-C)	1.90
177.0	403.2	9.0	1.86	(I-C)	2.03
186.0	403.2	9.0	1.94	(I-C)	2.13
195.0	403.2	9.0	2.02	(I-C)	2.22
203.0	403.2	8.0	2.09	(I-C)	2.34
212.0	403.2	9.0	2.18	(I-C)	2.41

Calculation stopped at time= 220.0 seconds.
Total number of lightning strokes = 11

pressure	radar	P(mm/hr)
617.	56.8	0.679
601.	56.6	0.651
586.	56.4	0.623
571.	56.2	0.596
557.	56.0	0.570
543.	55.8	0.544
529.	55.6	0.518
515.	55.5	0.492
501.	55.3	0.467
488.	55.1	0.442
475.	54.9	0.417
463.	54.8	0.392
450.	54.7	0.367
438.	54.6	0.341
426.	54.5	0.314
415.	55.1	0.251
403.	60.8	0.464E-01

Fletcher Glaciation Run
Fletcher x 50.0
Cell Radius = 1000.0 m.
updraft speed = 10.0 m/s
freezing level= 616.8 mb: balance level= 403.2mb
time step= 10.0s
Hailstone Flux = 0.500E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse= 258.0 K. Ql= 0.120E-02 kg m**-3
charge destroyed is 0.10 times that in a layer 1800.0
meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.859E-03

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut

1370.0	403.2	1370.0	1.61	(I-C)	1.17

Calculation stopped at time= 3600.0 seconds.
Total number of lightning strokes = 1

Precipitation reaches the ground at 1391.0 s.
Current to ground=-0.249E+07fC/m**2/s
Rain intensity at the ground= 2.10 mm/hr

pressure	radar	P(mm/hr)
617.	56.8	0.679
601.	56.6	0.651
586.	56.4	0.623
571.	56.2	0.596
557.	56.0	0.570
543.	55.8	0.544
529.	55.6	0.518
515.	55.5	0.492
501.	55.3	0.467
488.	55.1	0.442
475.	54.9	0.417
463.	54.8	0.392
450.	54.7	0.367
438.	54.6	0.341
426.	54.5	0.314
415.	55.1	0.251
403.	60.8	0.464E-01

Fletcher Glaciation Run
Fletcher x 0.100E+04
Cell Radius = 1000.0 m.
updraft speed = 10.0 m/s
freezing level= 616.8 mb: balance level= 403.2mb
time step= 10.0s
Hailstone Flux = 0.500E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse= 258.0 K. Ql= 0.120E-02 kg m**-3
charge destroyed is 0.10 times that in a layer 1800.0
meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.172E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
80.0	403.2	80.0	1.78	(I-C)	1.13
81.0	403.2	1.0	1.73	(I-C)	1.28
84.0	403.2	3.0	1.74	(I-C)	1.40
88.0	403.2	4.0	1.79	(I-C)	1.50
91.0	403.2	3.0	1.81	(I-C)	1.59
95.0	403.2	4.0	1.86	(I-C)	1.68
99.0	403.2	4.0	1.92	(I-C)	1.75
102.0	403.2	3.0	1.94	(I-C)	1.83
105.0	403.2	3.0	1.97	(I-C)	1.91
109.0	403.2	4.0	2.03	(I-C)	1.97

Calculation stopped at time= 112.0 seconds.

Total number of lightning strokes = 11

pressure	radar	P(mm/hr)
501.	52.7	0.255
488.	55.1	0.442
475.	54.9	0.417
463.	54.8	0.392
450.	54.7	0.367
438.	54.6	0.341
426.	54.5	0.314
415.	55.1	0.251
403.	60.8	0.464E-01

Fletcher Glaciation Run
Fletcher x 100.
Cell Radius = 1000.0 m.
updraft speed = 10.0 m/s
freezing level= 616.8 mb: balance level= 403.2mb
time step= 10.0s
Hailstone Flux = 0.100E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse= 258.0 K. Ql= 0.120E-02 kg m**-3
charge destroyed is 0.10 times that in a layer 1800.0
meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.152E-02

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut

Calculation stopped at time= 3600.0 seconds.
Total number of lightning strokes = 0

Precipitation reaches the ground at 1580.0 s.
Current to ground=-0.995E+06fC/m**2/s
Rain intensity at the ground= 0.420 mm/hr

Hallett-Mossop Run
Hallett factor = 0.500E+15
Cell Radius = 1000.0 m.
updraft speed = 10.0 m/s
freezing level= 616.8 mb: balance level= 403.2mb
time step= 10.0s
Hailstone Flux = 0.500E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse= 258.0 K. Ql= 0.120E-02 kg m**-3
charge destroyed is 0.10 times that in a layer 1800.0 meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.314E-02

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
360.0	403.2	360.0	1.65	(I-C)	1.91
789.0	403.2	429.0	3.92	(I-C)	1.72
852.0	403.2	63.0	4.30	(I-C)	2.89
900.0	403.2	48.0	4.61	(C-G)	3.83
929.0	403.2	29.0	5.25	(C-G)	5.62
952.0	403.2	23.0	5.94	(C-G)	7.68
953.0	450.2	1.0	6.22	(I-C)	12.1
996.0	403.2	43.0	6.52	(C-G)	7.25
997.0	450.2	1.0	6.83	(C-G)	12.2
1036.0	403.2	39.0	7.88	(C-G)	9.61

Calculation stopped at time= 1037.0 seconds.
Total number of lightning strokes = 11

Precipitation reaches the ground at 482.0 s.
Current to ground=-0.307E+08fC/m**2/s
Rain intensity at the ground= 2.10 mm/hr

pressure	radar	P(mm/hr)
617.	56.8	0.679
601.	56.6	0.651
586.	56.4	0.623
571.	56.2	0.596
557.	56.0	0.570
543.	55.8	0.544
529.	55.6	0.518
515.	55.5	0.492
501.	55.3	0.467
488.	55.1	0.442
475.	54.9	0.417
463.	54.8	0.392
450.	54.7	0.367
438.	54.6	0.341
426.	54.5	0.314

```
  415.       55.1      0.251
  403.       60.8      0.464E-01
Hallett-Mossop Run
Hallett factor = 0.100E+15
Cell Radius =  1000.0 m.
updraft speed =   10.0 m/s
freezing level=  616.8 mb: balance level=  403.2mb
time step=   10.0s
Hailstone Flux = 0.500E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse=  258.0 K. Ql= 0.120E-02 kg m**-3
charge destroyed is      0.10 times that in a           layer 1800.0
meters deep just below cloud top.


Charge parameter==Zp*RN*a**1.5 = 0.627E-03

   Time(s)    p(mb)  Interval(s) Qzap(C)    Type tauq/taut


   2420.0     403.2    2420.0     2.37        (I-C)    1.72


Calculation stopped at time= 3600.0 seconds.
Total number of lightning strokes =    1

Precipitation reaches the ground at 1580.0 s.
Current to ground=-0.573E+07fC/m**2/s
Rain intensity at the ground=  2.10     mm/hr

  pressure      radar      P(mm/hr)

  617.       56.8      0.679
  601.       56.6      0.651
  586.       56.4      0.623
  571.       56.2      0.596
  557.       56.0      0.570
  543.       55.8      0.544
  529.       55.6      0.518
  515.       55.5      0.492
  501.       55.3      0.467
  488.       55.1      0.442
  475.       54.9      0.417
  463.       54.8      0.392
  450.       54.7      0.367
  438.       54.6      0.341
  426.       54.5      0.314
  415.       55.1      0.251
  403.       60.8      0.464E-01
Hallett-Mossop Run
Hallett factor = 0.100E+16
Cell Radius =  1000.0 m.
updraft speed =   10.0 m/s
freezing level=  616.8 mb: balance level=  403.2mb
time step=   10.0s
Hailstone Flux = 0.500E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse=  258.0 K. Ql= 0.120E-02 kg m**-3
charge destroyed is      0.10 times that in a           layer 1800.0
meters deep just below cloud top.
```

Charge parameter==Zp*RN*a**1.5 = 0.627E-02

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
200.0	403.2	200.0	1.67	(I-C)	1.67
243.0	403.2	43.0	2.10	(I-C)	2.13
289.0	403.2	46.0	2.62	(I-C)	2.40
325.0	403.2	36.0	3.04	(I-C)	2.78
356.0	403.2	31.0	3.41	(I-C)	3.17
384.0	403.2	28.0	3.76	(I-C)	3.55
409.0	403.2	25.0	4.08	(I-C)	3.94
432.0	403.2	23.0	4.37	(I-C)	4.35
454.0	403.2	22.0	4.67	(I-C)	4.74
475.0	403.2	21.0	4.96	(C-G)	5.13

Calculation stopped at time= 491.0 seconds.
Total number of lightning strokes = 11

Precipitation reaches the ground at 338.0 s.
Current to ground=-0.352E+08fC/m**2/s
Rain intensity at the ground= 2.10 mm/hr

pressure	radar	P(mm/hr)
617.	56.8	0.679
601.	56.6	0.651
586.	56.4	0.623
571.	56.2	0.596
557.	56.0	0.570
543.	55.8	0.544
529.	55.6	0.518
515.	55.5	0.492
501.	55.3	0.467
488.	55.1	0.442
475.	54.9	0.417
463.	54.8	0.392
450.	54.7	0.367
438.	54.6	0.341
426.	54.5	0.314
415.	55.1	0.251
403.	60.8	0.464E-01

Hallett-Mossop Run
Hallett factor = 0.450E+16
Cell Radius = 1000.0 m.
updraft speed = 10.0 m/s
freezing level= 616.8 mb: balance level= 403.2mb
time step= 10.0s
Hailstone Flux = 0.500E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse= 258.0 K. Ql= 0.120E-02 kg m**-3
charge destroyed is 0.10 times that in a layer 1800.0
meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.282E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
70.0	403.2	70.0	2.26	(I-C)	1.40
71.0	403.2	1.0	2.17	(I-C)	1.44
73.0	403.2	2.0	2.13	(I-C)	1.50
77.0	403.2	4.0	2.21	(I-C)	1.61
82.0	403.2	5.0	2.35	(I-C)	1.76
88.0	403.2	6.0	2.57	(I-C)	1.93
93.0	403.2	5.0	2.74	(I-C)	2.07
99.0	403.2	6.0	2.98	(I-C)	2.23
105.0	403.2	6.0	3.23	(I-C)	2.39
111.0	403.2	6.0	3.48	(I-C)	2.54

Calculation stopped at time= 117.0 seconds.
Total number of lightning strokes = 11

pressure	radar	P(mm/hr)
529.	55.8	0.533
515.	55.5	0.492
501.	55.3	0.467
488.	55.1	0.442
475.	54.9	0.417
463.	54.8	0.392
450.	54.7	0.367
438.	54.6	0.341
426.	54.5	0.314
415.	55.1	0.251
403.	60.8	0.464E-01

Hallett-Mossop Run
Hallett factor = 0.450E+16
Cell Radius = 200.0 m.
updraft speed = 10.0 m/s
freezing level= 616.8 mb: balance level= 414.6mb
time step= 10.0s
Hailstone Flux = 0.100E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse= 258.0 K. Ql= 0.130E-02 kg m**-3
charge destroyed is 0.10 times that in a layer 1800.0 meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.453E-02

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
770.0	414.6	770.0	0.228	(I-C)	1.58
3304.0	414.6	2534.0	0.940	(I-C)	1.57
3402.0	414.6	98.0	0.991	(C-G)	3.05
3462.0	414.6	60.0	1.13	(C-G)	6.89
3508.0	414.6	46.0	1.28	(C-G)	11.1
3547.0	414.6	39.0	1.45	(C-G)	15.6
3581.0	414.6	34.0	1.63	(C-G)	20.7

Calculation stopped at time= 3600.0 seconds.
Total number of lightning strokes = 7

Precipitation reaches the ground at 845.0 s.
Current to ground=-0.407E+08fC/m**2/s
Rain intensity at the ground= 0.430 mm/hr

pressure	radar	P(mm/hr)
617.	49.9	0.138
601.	49.7	0.132
586.	49.5	0.126
571.	49.3	0.120
557.	49.0	0.115
543.	48.8	0.109
529.	48.6	0.103
515.	48.4	0.978E-01
501.	48.3	0.923E-01
488.	48.1	0.869E-01
475.	47.9	0.814E-01
463.	47.7	0.760E-01
450.	47.6	0.704E-01
438.	47.6	0.645E-01
426.	48.0	0.511E-01
415.	53.6	0.881E-02

Hallett-Mossop Run
Hallett factor = 0.450E+16
Cell Radius = 400.0 m.
updraft speed = 10.0 m/s
freezing level= 616.8 mb: balance level= 414.6mb
time step= 10.0s
Hailstone Flux = 0.100E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse= 258.0 K. Ql= 0.130E-02 kg m**-3
charge destroyed is 0.10 times that in a layer 1800.0 meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.906E-02

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
360.0	414.6	360.0	0.419	(I-C)	1.89
1192.0	414.6	832.0	1.39	(I-C)	1.57
1271.0	414.6	79.0	1.51	(I-C)	2.59
1334.0	414.6	63.0	1.61	(I-C)	3.45
1389.0	414.6	55.0	1.71	(C-G)	4.21
1427.0	414.6	38.0	1.95	(C-G)	6.13
1459.0	414.6	32.0	2.22	(C-G)	8.25
1487.0	414.6	28.0	2.51	(C-G)	10.6
1512.0	414.6	25.0	2.83	(C-G)	13.3
1513.0	462.6	1.0	2.97	(I-C)	21.7

Calculation stopped at time= 1551.0 seconds.
Total number of lightning strokes = 11

Precipitation reaches the ground at 476.0 s.
Current to ground=-0.496E+08fC/m**2/s
Rain intensity at the ground= 0.430 mm/hr

pressure	radar	P(mm/hr)
617.	49.9	0.138
601.	49.7	0.132
586.	49.5	0.126
571.	49.3	0.120
557.	49.0	0.115
543.	48.8	0.109
529.	48.6	0.103
515.	48.4	0.978E-01
501.	48.3	0.923E-01
488.	48.1	0.869E-01
475.	47.9	0.814E-01
463.	47.7	0.760E-01
450.	47.6	0.704E-01
438.	47.6	0.645E-01
426.	48.0	0.511E-01
415.	53.6	0.881E-02

Hallett-Mossop Run
Hallett factor = 0.450E+16
Cell Radius = 600.0 m.
updraft speed = 10.0 m/s

freezing level= 616.8 mb: balance level= 414.6mb
time step= 10.0s
Hailstone Flux = 0.100E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse= 258.0 K. Ql= 0.130E-02 kg m**-3
charge destroyed is 0.10 times that in a layer 1800.0 meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.136E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
280.0	414.6	280.0	0.703	(I-C)	1.80
702.0	414.6	422.0	1.86	(I-C)	1.57
771.0	414.6	69.0	2.07	(I-C)	2.39
824.0	414.6	53.0	2.24	(I-C)	3.11
870.0	414.6	46.0	2.41	(I-C)	3.73
911.0	414.6	41.0	2.56	(I-C)	4.33
948.0	414.6	37.0	2.70	(C-G)	4.97
975.0	414.6	27.0	3.08	(C-G)	6.41
999.0	414.6	24.0	3.49	(C-G)	8.07
1021.0	414.6	22.0	3.96	(C-G)	9.88

Calculation stopped at time= 1022.0 seconds.
Total number of lightning strokes = 11

Precipitation reaches the ground at 404.0 s.
Current to ground=-0.433E+08fC/m**2/s
Rain intensity at the ground= 0.430 mm/hr

pressure	radar	P(mm/hr)
617.	49.9	0.138
601.	49.7	0.132
586.	49.5	0.126
571.	49.3	0.120
557.	49.0	0.115
543.	48.8	0.109
529.	48.6	0.103
515.	48.4	0.978E-01
501.	48.3	0.923E-01
488.	48.1	0.869E-01
475.	47.9	0.814E-01
463.	47.7	0.760E-01
450.	47.6	0.704E-01
438.	47.6	0.645E-01
426.	48.0	0.511E-01
415.	53.6	0.881E-02

Hallett-Mossop Run
Hallett factor = 0.450E+16
Cell Radius = 800.0 m.
updraft speed = 10.0 m/s
freezing level= 616.8 mb: balance level= 414.6mb
time step= 10.0s
Hailstone Flux = 0.100E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse= 258.0 K. Ql= 0.130E-02 kg m**-3

charge destroyed is 0.10 times that in a layer 1800.0 meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.181E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
240.0	414.6	240.0	1.04	(I-C)	1.75
474.0	414.6	234.0	2.25	(I-C)	1.64
536.0	414.6	62.0	2.57	(I-C)	2.27
583.0	414.6	47.0	2.82	(I-C)	2.85
624.0	414.6	41.0	3.06	(I-C)	3.35
660.0	414.6	36.0	3.28	(I-C)	3.88
693.0	414.6	33.0	3.49	(I-C)	4.38
724.0	414.6	31.0	3.70	(C-G)	4.86
746.0	414.6	22.0	4.21	(C-G)	6.11
766.0	414.6	20.0	4.77	(C-G)	7.51

ulation stopped at time= 767.0 seconds.
al number of lightning strokes = 11

Precipitation reaches the ground at 368.0 s.
Current to ground=-0.380E+08fC/m**2/s
Rain intensity at the ground= 0.430 mm/hr

pressure	radar	P(mm/hr)
617.	49.9	0.138
601.	49.7	0.132
586.	49.5	0.126
571.	49.3	0.120
557.	49.0	0.115
543.	48.8	0.109
529.	48.6	0.103
515.	48.4	0.978E-01
501.	48.3	0.923E-01
488.	48.1	0.869E-01
475.	47.9	0.814E-01
463.	47.7	0.760E-01
450.	47.6	0.704E-01
438.	47.6	0.645E-01
426.	48.0	0.511E-01
415.	53.6	0.881E-02

Hallett-Mossop Run
Hallett factor = 0.450E+16
Cell Radius = 1000.0 m.
updraft speed = 10.0 m/s
freezing level= 616.8 mb: balance level= 392.0mb
time step= 10.0s
Hailstone Flux = 0.100E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse= 258.0 K. Ql= 0.110E-02 kg m**-3
charge destroyed is 0.10 times that in a layer 1800.0
meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.272E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
190.0	392.0	190.0	1.59	(I-C)	1.62
227.0	392.0	37.0	1.95	(I-C)	2.09
266.0	392.0	39.0	2.38	(I-C)	2.39
300.0	392.0	34.0	2.78	(I-C)	2.74
330.0	392.0	30.0	3.16	(I-C)	3.14
357.0	392.0	27.0	3.51	(I-C)	3.53
381.0	392.0	24.0	3.84	(I-C)	3.95
404.0	392.0	23.0	4.16	(I-C)	4.34
425.0	392.0	21.0	4.46	(I-C)	4.75
445.0	392.0	20.0	4.76	(C-G)	5.16

Calculation stopped at time= 460.0 seconds.
Total number of lightning strokes = 11

Precipitation reaches the ground at 340.0 s.
Current to ground=-0.317E+08fC/m**2/s
Rain intensity at the ground= 0.407 mm/hr

pressure	radar	P(mm/hr)
617.	49.7	0.133
601.	49.5	0.127
586.	49.3	0.122
571.	49.2	0.117
557.	49.0	0.113
543.	48.8	0.108
529.	48.6	0.103
515.	48.5	0.984E-01
501.	48.3	0.938E-01
488.	48.1	0.892E-01
475.	48.0	0.846E-01
463.	47.9	0.801E-01
450.	47.7	0.755E-01
438.	47.6	0.709E-01
426.	47.6	0.661E-01
415.	47.6	0.611E-01

403.	48.2	0.495E-01
392.	54.1	0.979E-02

Fletcher Glaciation Run
Fletcher x 0.100E+04
Cell Radius = 1000.0 m.
updraft speed = 10.0 m/s
freezing level= 616.8 mb: balance level= 392.0mb
time step= 10.0s
Hailstone Flux = 0.100E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse= 258.0 K. Ql= 0.110E-02 kg m**-3
charge destroyed is 0.10 times that in a layer 1800.0
meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.375E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
130.0	392.0	130.0	1.53	(I-C)	1.15
131.0	392.0	1.0	1.48	(I-C)	1.46
138.0	392.0	7.0	1.53	(I-C)	1.65
146.0	392.0	8.0	1.60	(I-C)	1.79
154.0	392.0	8.0	1.67	(I-C)	1.92
161.0	392.0	7.0	1.73	(I-C)	2.04
168.0	392.0	7.0	1.79	(I-C)	2.15
175.0	392.0	7.0	1.85	(I-C)	2.25
182.0	392.0	7.0	1.91	(I-C)	2.34
189.0	392.0	7.0	1.97	(I-C)	2.42

Calculation stopped at time= 195.0 seconds.
Total number of lightning strokes = 11

pressure	radar	P(mm/hr)
571.	48.9	0.111
557.	49.0	0.113
543.	48.8	0.108
529.	48.6	0.103
515.	48.5	0.984E-01
501.	48.3	0.938E-01
488.	48.1	0.892E-01
475.	48.0	0.846E-01
463.	47.9	0.801E-01
450.	47.7	0.755E-01
438.	47.6	0.709E-01
426.	47.6	0.661E-01
415.	47.6	0.611E-01
403.	48.2	0.495E-01
392.	54.1	0.979E-02

Hallett-Mossop Run
Hallett factor = 0.450E+16
Cell Radius = 1000.0 m.
updraft speed = 9.0 m/s
freezing level= 616.8 mb: balance level= 403.2mb
time step= 10.0s
Hailstone Flux = 0.100E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m

Treverse= 258.0 K. Ql= 0.650E-03 kg m**-3
charge destroyed is 0.10 times that in a layer 1800.0
meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.285E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
250.0	403.2	250.0	1.56	(I-C)	1.53
283.0	403.2	33.0	1.78	(I-C)	2.08
319.0	403.2	36.0	2.07	(I-C)	2.43
352.0	403.2	33.0	2.35	(I-C)	2.73
383.0	403.2	31.0	2.62	(I-C)	3.04
411.0	403.2	28.0	2.87	(I-C)	3.37
437.0	403.2	26.0	3.12	(I-C)	3.71
462.0	403.2	25.0	3.36	(I-C)	4.04
486.0	403.2	24.0	3.60	(I-C)	4.36
509.0	403.2	23.0	3.84	(I-C)	4.68

Calculation stopped at time= 531.0 seconds.
Total number of lightning strokes = 11

Precipitation reaches the ground at 459.0 s.
Current to ground=-0.256E+08fC/m**2/s
Rain intensity at the ground= 0.286 mm/hr

pressure	radar	P(mm/hr)
617.	46.3	0.751E-01
601.	46.2	0.726E-01
586.	46.1	0.701E-01
571.	46.0	0.677E-01
557.	45.9	0.653E-01
543.	45.8	0.629E-01
529.	45.7	0.605E-01
515.	45.6	0.581E-01
501.	45.5	0.557E-01
488.	45.4	0.534E-01
475.	45.3	0.510E-01
463.	45.3	0.485E-01
450.	45.3	0.460E-01
438.	45.3	0.435E-01
426.	45.4	0.407E-01
415.	46.4	0.342E-01
403.	52.7	0.970E-02

Fletcher Glaciation Run
Fletcher x 0.100E+04
Cell Radius = 1000.0 m.
updraft speed = 9.0 m/s
freezing level= 616.8 mb: balance level= 403.2mb
time step= 10.0s
Hailstone Flux = 0.100E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse= 258.0 K. Ql= 0.650E-03 kg m**-3
charge destroyed is 0.10 times that in a layer 1800.0
meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.174E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
330.0	403.2	330.0	1.32	(I-C)	1.14
398.0	403.2	68.0	1.58	(I-C)	1.27
507.0	403.2	109.0	2.02	(I-C)	1.19
585.0	403.2	78.0	2.32	(I-C)	1.29
643.0	403.2	58.0	2.53	(I-C)	1.48
690.0	403.2	47.0	2.70	(I-C)	1.70
731.0	403.2	41.0	2.84	(I-C)	1.91
768.0	403.2	37.0	2.96	(I-C)	2.11
802.0	403.2	34.0	3.08	(I-C)	2.30
834.0	403.2	32.0	3.18	(I-C)	2.47

Calculation stopped at time= 864.0 seconds.
Total number of lightning strokes = 11

Precipitation reaches the ground at 531.0 s.
Current to ground=-0.797E+07fC/m**2/s
Rain intensity at the ground= 0.286 mm/hr

pressure	radar	P(mm/hr)
617.	46.3	0.751E-01
601.	46.2	0.726E-01
586.	46.1	0.701E-01
571.	46.0	0.677E-01
557.	45.9	0.653E-01
543.	45.8	0.629E-01
529.	45.7	0.605E-01
515.	45.6	0.581E-01
501.	45.5	0.557E-01
488.	45.4	0.534E-01
475.	45.3	0.510E-01
463.	45.3	0.485E-01
450.	45.3	0.460E-01
438.	45.3	0.435E-01
426.	45.4	0.407E-01
415.	46.4	0.342E-01
403.	52.7	0.970E-02

Fletcher Glaciation Run
Fletcher x 0.100E+04
Cell Radius = 1000.0 m.
updraft speed = 9.0 m/s
freezing level= 616.8 mb: balance level= 392.0mb
time step= 10.0s
Hailstone Flux = 0.100E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse= 258.0 K. Ql= 0.600E-03 kg m**-3
charge destroyed is 0.10 times that in a layer 1800.0
meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.429E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut

140.0	392.0	140.0	1.42	(I-C)	1.13
148.0	392.0	8.0	1.46	(I-C)	1.38
157.0	392.0	9.0	1.52	(I-C)	1.57
165.0	392.0	8.0	1.57	(I-C)	1.75
173.0	392.0	8.0	1.62	(I-C)	1.89
180.0	392.0	7.0	1.66	(I-C)	2.03
187.0	392.0	7.0	1.71	(I-C)	2.15
194.0	392.0	7.0	1.76	(I-C)	2.26
200.0	392.0	6.0	1.79	(I-C)	2.38
206.0	392.0	6.0	1.82	(I-C)	2.49

Calculation stopped at time= 212.0 seconds.
Total number of lightning strokes = 11

pressure	radar	P(mm/hr)
529.	43.1	0.337E-01
515.	45.6	0.582E-01
501.	45.5	0.560E-01
488.	45.4	0.538E-01
475.	45.3	0.516E-01
463.	45.3	0.494E-01
450.	45.3	0.472E-01
438.	45.3	0.449E-01
426.	45.3	0.425E-01
415.	45.5	0.399E-01
403.	46.5	0.338E-01
392.	52.9	0.102E-01

Hallett-Mossop Run
Hallett factor = 0.450E+16
Cell Radius = 1000.0 m.
updraft speed = 9.0 m/s
freezing level= 616.8 mb: balance level= 392.0mb
time step= 10.0s
Hailstone Flux = 0.100E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse= 258.0 K. Ql= 0.600E-03 kg m**-3
charge destroyed is 0.10 times that in a layer 1800.0
meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.311E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
220.0	392.0	220.0	1.52	(I-C)	1.50
242.0	392.0	22.0	1.66	(I-C)	1.99
270.0	392.0	28.0	1.90	(I-C)	2.38
295.0	392.0	25.0	2.12	(I-C)	2.69
319.0	392.0	24.0	2.35	(I-C)	2.99
342.0	392.0	23.0	2.58	(I-C)	3.29
364.0	392.0	22.0	2.81	(I-C)	3.60
385.0	392.0	21.0	3.05	(I-C)	3.92
405.0	392.0	20.0	3.27	(I-C)	4.25
424.0	392.0	19.0	3.49	(I-C)	4.59

Calculation stopped at time= 443.0 seconds.
Total number of lightning strokes = 11

Precipitation reaches the ground at 442.0 s.
Current to ground=-0.226E+08fC/m**2/s
Rain intensity at the ground= 0.280 mm/hr

pressure	radar	P(mm/hr)
617.	46.3	0.739E-01
601.	46.2	0.716E-01
586.	46.1	0.693E-01
571.	46.0	0.671E-01
557.	45.8	0.648E-01
543.	45.7	0.626E-01
529.	45.7	0.604E-01
515.	45.6	0.582E-01
501.	45.5	0.560E-01
488.	45.4	0.538E-01
475.	45.3	0.516E-01
463.	45.3	0.494E-01
450.	45.3	0.472E-01
438.	45.3	0.449E-01
426.	45.3	0.425E-01
415.	45.5	0.399E-01
403.	46.5	0.338E-01
392.	52.9	0.102E-01

Fletcher Glaciation Run
Fletcher x 0.100E+04
Cell Radius = 1000.0 m.
updraft speed = 12.0 m/s
freezing level= 616.8 mb: balance level= 403.2mb
time step= 10.0s
Hailstone Flux = 0.100E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse= 258.0 K. Ql= 0.270E-02 kg m**-3
charge destroyed is 0.10 times that in a layer 1800.0
meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.121E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
210.0	403.2	210.0	1.42	(I-C)	1.22
546.0	403.2	336.0	3.76	(I-C)	1.22
587.0	403.2	41.0	4.00	(I-C)	1.70
619.0	403.2	32.0	4.19	(I-C)	2.07
647.0	403.2	28.0	4.34	(I-C)	2.37
673.0	403.2	26.0	4.48	(C-G)	2.59
689.0	403.2	16.0	5.00	(C-G)	3.61
702.0	403.2	13.0	5.55	(C-G)	4.73
712.0	414.6	10.0	6.10	(C-G)	6.17
724.0	403.2	12.0	6.52	(C-G)	6.03

Calculation stopped at time= 725.0 seconds.
Total number of lightning strokes = 11

Precipitation reaches the ground at 300.0 s.
Current to ground=-0.652E+08fC/m**2/s
Rain intensity at the ground= 1.17 mm/hr

pressure	radar	P(mm/hr)
617.	55.9	0.363
601.	55.6	0.344
586.	55.3	0.325
571.	55.0	0.306
557.	54.7	0.289
543.	54.4	0.271
529.	54.1	0.255
515.	53.8	0.238
501.	53.5	0.222
488.	53.2	0.207
475.	52.9	0.192
463.	52.6	0.176
450.	52.3	0.162
438.	52.0	0.146
426.	51.7	0.131
415.	51.6	0.972E-01
403.	56.4	0.971E-02

Hallett-Mossop Run
Hallett factor = 0.450E+16
Cell Radius = 1000.0 m.
updraft speed = 12.0 m/s
freezing level= 616.8 mb: balance level= 403.2mb
time step= 10.0s
Hailstone Flux = 0.100E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse= 258.0 K. Ql= 0.270E-02 kg m**-3
charge destroyed is 0.10 times that in a layer 1800.0
meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.200E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
150.0	403.2	150.0	1.79	(I-C)	1.97
244.0	586.2	94.0	3.33	(I-C)	2.34
245.0	586.2	1.0	3.01	(I-C)	2.12
327.0	403.2	82.0	4.04	(I-C)	2.18
368.0	403.2	41.0	4.71	(I-C)	2.91
400.0	403.2	32.0	5.28	(C-G)	3.62
420.0	403.2	20.0	6.18	(C-G)	4.81
421.0	450.2	1.0	6.49	(C-G)	6.98
446.0	403.2	25.0	7.47	(C-G)	5.62
447.0	450.2	1.0	7.85	(C-G)	8.25

Calculation stopped at time= 448.0 seconds.
Total number of lightning strokes = 11

Precipitation reaches the ground at 246.0 s.
Current to ground=-0.239E+09fC/m**2/s
Rain intensity at the ground= 1.17 mm/hr

pressure	radar	P(mm/hr)
617.	55.9	0.363
601.	55.6	0.344
586.	55.3	0.325
571.	55.0	0.306
557.	54.7	0.289
543.	54.4	0.271
529.	54.1	0.255
515.	53.8	0.238
501.	53.5	0.222
488.	53.2	0.207
475.	52.9	0.192
463.	52.6	0.176
450.	52.3	0.162
438.	52.0	0.146
426.	51.7	0.131
415.	51.6	0.972E-01
403.	56.4	0.971E-02

Fletcher Glaciation Run
Fletcher x 0.100E+04
Cell Radius = 1000.0 m.
updraft speed = 11.0 m/s
freezing level= 616.8 mb: balance level= 403.2mb
time step= 10.0s
Hailstone Flux = 0.100E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse= 258.0 K. Ql= 0.190E-02 kg m**-3
charge destroyed is 0.10 times that in a layer 1800.0
meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.118E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
1830.0	403.2	1830.0	3.51	(C-G)	1.93
2488.0	403.2	658.0	5.13	(C-G)	1.93
2521.0	403.2	33.0	5.67	(C-G)	7.62
2522.0	426.2	1.0	6.05	(C-G)	27.1
2523.0	450.2	1.0	6.06	(C-G)	26.2
2575.0	414.6	52.0	6.94	(C-G)	17.3
2576.0	450.2	1.0	6.98	(I-C)	18.6
2620.0	414.6	44.0	7.46	(C-G)	23.0
2621.0	450.2	1.0	7.51	(C-G)	24.3
2622.0	475.2	1.0	7.56	(C-G)	25.5

Calculation stopped at time= 2623.0 seconds.
Total number of lightning strokes = 11

Precipitation reaches the ground at 1210.0 s.
Current to ground=-0.143E+08fC/m**2/s
Rain intensity at the ground= 0.634 mm/hr

pressure	radar	P(mm/hr)
617.	53.0	0.230

601.	52.8	0.219
586.	52.5	0.208
571.	52.3	0.197
557.	52.0	0.187
543.	51.8	0.177
529.	51.5	0.167
515.	51.3	0.158
501.	51.0	0.148
488.	50.7	0.139
475.	50.5	0.130
463.	50.3	0.121
450.	50.0	0.111
438.	49.8	0.102
426.	49.7	0.927E-01
415.	49.9	0.711E-01
403.	48.4	0.197E-02

Hallett-Mossop Run
Hallett factor = 0.450E+16
Cell Radius = 1000.0 m.
updraft speed = 11.0 m/s
freezing level= 616.8 mb: balance level= 403.2mb
time step= 10.0s
Hailstone Flux = 0.100E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse= 258.0 K. Ql= 0.190E-02 kg m**-3
charge destroyed is 0.10 times that in a layer 1800.0 meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.222E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
180.0	403.2	180.0	1.71	(I-C)	1.85
307.0	403.2	127.0	3.30	(I-C)	2.13
349.0	403.2	42.0	3.86	(I-C)	2.82
381.0	403.2	32.0	4.28	(I-C)	3.38
409.0	403.2	28.0	4.67	(C-G)	3.87
427.0	403.2	18.0	5.36	(C-G)	4.89
444.0	403.2	17.0	6.14	(C-G)	5.96
445.0	450.2	1.0	6.45	(I-C)	8.32
473.0	403.2	28.0	6.76	(C-G)	5.83
474.0	450.2	1.0	7.10	(C-G)	8.43

Calculation stopped at time= 475.0 seconds.
Total number of lightning strokes = 11

Precipitation reaches the ground at 283.0 s.
Current to ground=-0.601E+08fC/m**2/s
Rain intensity at the ground= 0.634 mm/hr

pressure	radar	P(mm/hr)
617.	53.0	0.230
601.	52.8	0.219
586.	52.5	0.208
571.	52.3	0.197
557.	52.0	0.187

543.	51.8	0.177
529.	51.5	0.167
515.	51.3	0.158
501.	51.0	0.148
488.	50.7	0.139
475.	50.5	0.130
463.	50.3	0.121
450.	50.0	0.111
438.	49.8	0.102
426.	49.7	0.927E-01
415.	49.9	0.711E-01
403.	55.1	0.933E-02

Fletcher Glaciation Run
Fletcher x 0.100E+04
Cell Radius = 1000.0 m.
updraft speed = 10.0 m/s
freezing level= 616.8 mb: balance level= 403.2mb
time step= 10.0s
Hailstone Flux = 0.100E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse= 258.0 K. Ql= 0.120E-02 kg m**-3
charge destroyed is 0.10 times that in a layer 1800.0
meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.152E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
300.0	403.2	300.0	1.39	(I-C)	1.17
694.0	403.2	394.0	3.24	(I-C)	1.17
747.0	403.2	53.0	3.46	(I-C)	1.60
789.0	403.2	42.0	3.62	(I-C)	1.92
825.0	403.2	36.0	3.76	(I-C)	2.22
857.0	403.2	32.0	3.87	(I-C)	2.49
887.0	403.2	30.0	3.98	(I-C)	2.71
915.0	403.2	28.0	4.08	(I-C)	2.93
942.0	403.2	27.0	4.17	(I-C)	3.11
967.0	403.2	25.0	4.25	(I-C)	3.34

Calculation stopped at time= 991.0 seconds.
Total number of lightning strokes = 11

Precipitation reaches the ground at 428.0 s.
Current to ground=-0.859E+07fC/m**2/s
Rain intensity at the ground= 0.420 mm/hr

pressure	radar	P(mm/hr)
617.	49.8	0.136
601.	49.6	0.130
586.	49.4	0.125
571.	49.2	0.119
557.	49.0	0.114
543.	48.8	0.109
529.	48.7	0.104
515.	48.5	0.985E-01
501.	48.3	0.934E-01

488.	48.1	0.884E-01
475.	48.0	0.835E-01
463.	47.8	0.784E-01
450.	47.7	0.734E-01
438.	47.6	0.682E-01
426.	47.6	0.628E-01
415.	48.1	0.503E-01
403.	53.9	0.927E-02

Hallett-Mossop Run
Hallett factor = 0.450E+16
Cell Radius = 1000.0 m.
updraft speed = 10.0 m/s
freezing level= 616.8 mb: balance level= 403.2mb
time step= 10.0s
Hailstone Flux = 0.100E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse= 258.0 K. Ql= 0.120E-02 kg m**-3
charge destroyed is 0.10 times that in a layer 1800.0
meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.250E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
220.0	403.2	220.0	1.67	(I-C)	1.70
284.0	403.2	64.0	2.29	(I-C)	2.07
337.0	403.2	53.0	2.84	(I-C)	2.41
378.0	403.2	41.0	3.28	(I-C)	2.83
411.0	403.2	33.0	3.63	(I-C)	3.28
441.0	403.2	30.0	3.97	(I-C)	3.68
468.0	403.2	27.0	4.28	(I-C)	4.11
493.0	403.2	25.0	4.58	(I-C)	4.54
517.0	403.2	24.0	4.87	(C-G)	4.95
534.0	403.2	17.0	5.55	(C-G)	5.99

Calculation stopped at time= 535.0 seconds.
Total number of lightning strokes = 11

Precipitation reaches the ground at 356.0 s.
Current to ground=-0.347E+08fC/m**2/s
Rain intensity at the ground= 0.420 mm/hr

pressure	radar	P(mm/hr)
617.	49.8	0.136
601.	49.6	0.130
586.	49.4	0.125
571.	49.2	0.119
557.	49.0	0.114
543.	48.8	0.109
529.	48.7	0.104
515.	48.5	0.985E-01
501.	48.3	0.934E-01
488.	48.1	0.884E-01
475.	48.0	0.835E-01
463.	47.8	0.784E-01
450.	47.7	0.734E-01

438.	47.6	0.682E-01
426.	47.6	0.628E-01
415.	48.1	0.503E-01
403.	53.9	0.927E-02